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The effect of ball characteristics on head acceleration during purposeful heading in male and female youth football players.

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The effect of ball characteristics on head acceleration during purposeful heading in male and female youth football players.

Abstract

The aim of this cross-sectional study was to explore the effects of different ball types and characteristics on head acceleration during purposeful heading in youth football players. Experienced male and female players (n=61) aged between 12-17 years completed heading trials with 4 different balls (Ball 1 mass 192 grams(g), pressure 5.0 pounds per square inch(psi); Ball 2 432g, 5.0psi; Ball 3 255g, 5.0psi; Ball 4 430g, 10.5psi) whilst wearing a head-mounted accelerometer and gyroscope. Balls 1, 2 and 4 were size 5 balls; Ball 3 was a size 4 ball. Multivariate analysis of variance and post-hoc univariate analyses revealed a statistically significant difference between ball type and head acceleration during heading for both linear acceleration (adjusted R^2=0.68; F=140.90; p=<0.001) and angular velocity (adjusted R^2=0.28; F=26.52; p=<0.001). Ball 1 (lightest size 5 ball) and Ball 3 (size 4 ball) demonstrated linear head accelerations up to 59% lower (p=<0.01) when compared with Ball 4 (size 5 regulated match ball). This study provides evidence that head acceleration during purposeful heading is influenced by changes to ball pressure, ball size and/or ball mass. Changing ball characteristics, particularly in youth football training when heading is being taught, should be an easy strategy to implement.

Key terms: Soccer; adolescent;; ball; head injury

Introduction

In Australia, there are 2 million registered football players with a total growth rate of 6% (11% in females) from 2018 to 2019 (Football Federation Australia., 2019). Considering the continued global popularity of football, player injury prevention has never been more important. Evidence-based, translational research is vitally important to identify sport-specific injury risk factors and aid in the development of preventative recommendations and strategies (McCall et al., 2015). Purposeful heading of the ball in football is a sport specific skill where the head is deliberately used to strike the ball in order to redirect it (Putukian et al., 2019). It is a complex skill requiring precise timing, coordination and strength, and may be performed while the player is standing, running, jumping or diving (Spiotta et al., 2012). Heading incidence rates (IR) per 1000 match hours in boys football in Australia have been shown to increase from 483 in under-10s to 1515 in under-12s (Peek et al., 2020c). For male youth players heading IR per 1000 match hours have ranged from 1523 in under-13s to 2117 in under-15s with IR for females ranging from 909 in under-13s to 2090 in under-17s (Peek et al., 2020d).

Although the vast majority of purposeful heading does not result in concussion (Comstock et al., 2015, Beaudouin et al., 2019a), there is concern that frequent purposeful heading in football could have long-term detrimental effects on brain function (Spiotta et al., 2012). There is conflicting evidence that frequent heading in football contributes to, and is associated with, worse cognitive outcomes on neuropsychological assessment as well as structural changes on brain imaging in the developing brain (Spiotta et al., 2012, Putukian et al., 2019, Maher et al., 2014). Nonetheless, a number of football organisations around the world, including United States (US) Soccer and the Football Associations of England, Scotland and Northern Ireland, have prohibited or restricted heading in child and youth players (Yang and Baugh, 2016, Caccese et al., 2018, Football Association (England). 2020). Whilst taking such an approach will prevent heading related injury in young players who are prohibited from performing this skill in training and/or games, it will not prevent such injury in adolescent players when heading is permitted. Additionally, players who have been prohibited from learning heading technique in training will not automatically know how to safely to head a ball once heading is permitted when guidelines are based solely on age and not skill development. Instead, there may be other modifiable injury reduction strategies which can offer a safer way to develop heading skills in young players whilst also reducing heading burden.

One such strategy is to explore the effect that different ball characteristics can have on head acceleration during heading. Specific ball requirements are stipulated by the International Football Association Board (IFAB) ‘Laws of the Game’(Shewchenko et al., 2005, International Football Association Board., 2020). The 2020/2021 Laws of the Game state a size 5 match ball must have a pressure equal to 8.5-15.6 pounds per square inch (psi) at sea level and weigh between 410-450 grams (g) (International Football Association Board., 2020). Smaller size 3 (311-340g) and 4 (350-390g) balls are recommended for younger players, with regulations usually determined by each country’s football association (Peek et al., 2020a). Most players will have transitioned to a size 5 ball by the time they reach 14-15 years of age (Peek et al., 2020a). In the only known study to explore the effect of changing ball pressure on head acceleration in adult amateur football players (n=7), linear head acceleration during purposeful heading decreased by 10% with a reduction in ball pressure of approximately 50% (from 15.91g at 11.0psi to 14.48g at 5.8psi) (Shewchenko et al., 2005).

Whilst heading remains an integral part of football, it is vital that we explore all injury reduction approaches, including ball characteristics, which may reduce injury risk during heading. Thus, this novel study examined the effects of different ball types and characteristics on head acceleration (i.e., linear acceleration and angular velocity) during purposeful heading in male and female youth football players. Ball characteristics that can demonstrate lower linear acceleration and lower angular velocity during heading training in youth players may offer a safer way to develop heading skills.

Methods

Study design and setting

This cross-sectional descriptive study was undertaken and reported in guidance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.(Von Elm et al., 2008)

All players registered with one high-level youth football club in New South Wales (NSW), Australia, were invited to participate. The club has male and female teams registered to play in the National Premier League (a competition for players aged under-13 upwards) in NSW with players considered to be of a high-skill level for their age. Club players train 3 times per week for 40 weeks of the year with a competitive playing season lasting approximately 22 weeks. Approval for the research was granted from the Human Research Ethics Committee at the xxxxx (Protocol Number: 2019/655). *(blind for peer review)* This study was performed in accordance with the standards of ethics outlined in the Declaration of Helsinki.

Recruitment

All male and female players registered with the football club (n = 122) who were between the ages of 12–17 years were sent an email invitation to participate, which included information regarding the aims and requirements of the study. Players were excluded if they reported a recent concussion or other head or neck injury (within last 28 days). Written consent was obtained prior to data collection from both the player and their parent/legal guardian.

Data collection

Data were collected during July 2020 at the start of the resumption of training and competition following a delayed season commencement date due to community sport restrictions implemented in response to the COVID-19 pandemic.

Measures

Anthropometry data, which included height (Seca 217®, Germany) and body mass (BF-522 Tanita®, Japan), were collected under the same external conditions. Players wore their standard training kit consisting of light-weight shirt and shorts. A face-to-face survey with the first author (an experienced physiotherapist) was completed by each player prior to the heading trials to confirm eligibility and to obtain socio-demographic data including player self-reported heading exposure. To determine heading exposure, we asked all players the same open-ended question "how many headers do you perform on average per week including both practice and games?". Heading trials were completed using a tri-axial accelerometer and tri-axial gyroscope motion sensor (Axivity™).

Heading trials

Four balls were used in the heading trials. Balls 1 and 2 were selected as they were commercially available and affordable size 5 balls (approximately $20AUD each) purchased from well-known sports stores. These 2 balls also demonstrated a large difference in ball mass and represented balls that were marketed to players (particularly young players) to use when playing and practising ball skills at home. Ball 3 was a size 4 ball developed specifically by the developer for heading. Ball 4 was a size 5 ball which conformed to IFAB match ball regulations and similar to the one used in youth football matches in which this club participated. All balls were inflated to a range that was within the manufacturer's recommendations (Table 1).

** insert table 1 here**

Heading trials were supervised by the first author using a standardised procedure which was refined during earlier pilot testing within the University's biomechanics laboratory. A close fitting elastic 'swim cap' which housed a motion sensor (AX6™, Axivity™, Newcastle, UK), measuring linear acceleration (tri-axial accelerometer) and angular velocity (tri-axial gyroscope), was placed on the player's head, ensuring that the accelerometer was positioned centrally at the base of the occiput. This location was chosen given the size of the accelerator and that it was an easy anatomical marker to locate between players. A pro-licensed football coach, who was ex-international player, delivered the balls in this study using an overhead throw-in. Throw-ins were used in favour of a ball pitching machine to replicate a game scenario as used in earlier research (Dezman et al., 2013). Between 10-28% of headers are from balls delivered by a throw-in in football in Australia for players aged 12-17 years (Peek et al., 2020d). Players were asked to stand within a 1x1 metre box which was positioned 5 metres from the sideline on a standard outdoor football pitch. From within this box, players were asked to head a total of 9 balls (3 headers were completed with Ball 1, Ball 2 and Ball 3 in that order). Players could then opt to head Ball 4 a maximum of 3 times. Players were given the choice on whether to head this higher-pressure ball (Ball 4) as heading burden was highlighted as a concern during pilot testing. Players were instructed to keep their feet grounded and to stay inside the box but otherwise they could adopt any standing position or technique to head each ball. Players were instructed to leave any balls that they were not comfortable heading. Before players commenced the heading trials, each player was provided with the same game scenario communicated to them by the first author:

> "*Imagine that you are in a game, the ball has gone out of play and your team-mate is about to throw the ball to you from the side-line. You are going to head the ball back to your team-mate's feet so that they can play on."*

This meant that the ball had to be headed back in the direction of the throw, i.e. a 180-degree change in ball direction.

A data recording sheet was used by a member of the research team to record each header with fields which included: time of header (hour: minute: seconds), ball number, player name and date of birth, and whether the header was valid. For headers to be valid, players had to receive the ball on their forehead (as opposed to the top or side of the head), not move their feet and be located inside the box when heading the ball. Invalid headers were only repeated if the ball did not contact the player's head to reduce the heading burden from multiple attempts. The 3 (or 4) balls were delivered in the same order for every player.

Linear accelerations were sampled at 800Hz in the ±16g range for each axis with gyroscope data sampled at 800Hz (±1000 degrees per second). Once players had completed the heading trials, data from the accelerometer were downloaded to the OmGui software (Axivity™, Newcastle, UK) as a Continuous Wave Accelerometer (*.cwa) file containing time series data of linear accelerations along each orthogonal axis as well as the gyroscope data. Accelerometer and gyroscope data corresponding to each header (confirmed by matching the time on the trace to the time on the data recording sheet) were exported into excel as *.csv files and processed in MATLAB (R2020a, Mathworks Inc.™) by the last author blinded to data collection and order of ball delivery. Following a review of the raw data and removal of trials with clipped data (i.e. linear accelerations greater than 16g or angular velocities greater than 1000 degrees along any individual axis), resultant linear acceleration and angular velocity were calculated from the raw data using the Pythagorean equation. Peak resultant acceleration and angular velocity were extracted from each heading trial to represent head acceleration. Figure 1 shows an example of a heading trace for one player for resultant linear acceleration.

insert figure 1 here

Intra-tester reliability

A subset of 40 headers (see power calculation below) from different players (10 with each ball) were captured using slow motion video and analysed using the stopwatch function in Runmatic™ (a smart phone app). Using the slow motion video of a selection of headers, we were able to calculate the time taken for the ball to travel the 5 metre distance from the point the ball left the hands of the throw-in coach to the moment the ball made contact with the player's head. These data were then used to calculate intra-tester reliability of the speed of each recorded throw in.

Sample size

An *a priori* sample size calculation was performed using PASS 2019 (version 19.0.3, Germany) using a moderate effect size (d>0.07) based on earlier studies (Muller et al., 1992, Becker et al., 2019). Using a multivariate analysis of variance (MANOVA) (power of 0.90, $\alpha = 0.05$) a minimum group size of 40 participants was required to demonstrate a change in head acceleration during heading. This sample size was increased to 48 to account for a 20% possibility of invalid headers or equipment error.

Data analysis

Analyses were performed using Stata 14.0 (College Station, Texas, USA). Descriptive data for participant socio-demographics are presented using counts, means and standard deviations. Baseline differences in sex characteristics measures were analysed by t-tests for continuous variables. The level of significance was set at $\alpha=0.05$.

The intra-rater reliability of throw-ins was analysed using a 2-way mixed effects model to determine the intra-class correlation coefficient (ICC) with magnitudes interpreted as poor (less than 0.50), moderate (0.50–0.75), good (0.75–0.90) and excellent (more than 0.90) (Koo and Li, 2016).

One-way multivariate analysis of variance (MANOVA) with mean peak linear acceleration and angular velocity as dependent variables and ball type as the independent variable was used to analyse the combined male and female data. One-way MANOVA within each sex was then completed. To reveal significant differences in the dependent variables between balls, separate univariate ANOVAs were used. Finally, an independent t-test was performed to determine whether there was a significant difference in linear acceleration (or angular velocity) based on ball type (using first Ball 4 and then Ball 2 as the reference ball). Balls 2 and 4 were chosen as the reference balls as both were size 5 balls which conformed to IFAB regulations for ball mass. Ball 4 also conformed for pressure. Additionally, all players headed Ball 2 whereas only males headed Ball 4.

To determine which variables predicted linear acceleration and angular velocity, separate direct-entry multiple regression analyses were conducted for ball pressure, ball mass, ball size, sex, age and headers performed per week. Means (SD), F-values, R^2 and p-values are reported with level of significance set *a priori* at $\alpha=0.05$.

Results

From 122 players invited to participate, 62 players and their guardians provided consent. One player was excluded due to a recent diagnosis of concussion sustained whilst at school in the previous week, leaving 61 players who completed heading trials.

From a total of 624 headers, 23 headers (3.6%) were deemed invalid (18 for point of contact with the top of the player's head and 5 because the player moved outside of the box). In addition, 12 headers exceeded the maximum thresholds of the Axivity™ for either linear acceleration, angular velocity or both. These 12 headers were mainly observed in younger male players, and all but 2 headers were for Ball 4. This left a total of 589 headers included in the analysis. All players recorded at least 2 headers per ball for Balls 1 and 2; 10 males did not head Ball 3 or 4; and none of the females opted to head Ball 4. The main reason for declining was that players wanted to reduce the number of headers during testing.

Slow-motion analyses revealed minimal differences between ball speeds for each of the 4 ball types. The mean speed for all balls during a throw-in was 6.25m/s or 22.5 km/h with speeds ranging from 5.95 to 6.41 m/s. This speed was consistent with earlier reported ball speeds of 6.8m/s (± 0.5m/s) from a throw-in with a slighter greater distance of 6.5m.(Bauer et al., 2001) The ICC for throw-ins was calculated at 0.76 (95%CI 0.70-0.82) demonstrating good reliability.

Player socio-demographics

Table 2 summarises the socio-demographic data for male and female players separately and combined. Differences between males and females for age (p=0.95), body mass (p=0.15), football playing experience (p=0.64) and training volume (p=0.22) were non-significant. However, there were statistically significant differences between males and females for height (p=0.01) and self-reported number of headers performed per week (p=0.02), with female players self-reporting a mean of 5 headers compared with 10 headers for male players.

insert table 2 here

The effect of ball type

Results revealed a statistically significant difference between ball type and the dependent variables (F=53.68; p=<0.001). Post-hoc univariate analyses revealed statistically significant differences for linear acceleration (adjusted R^2=0.68; F=140.90; p=<0.001) and angular velocity (adjusted R^2=0.28; F=26.52; p=<0.001). The result of the one-way MANOVA by sex demonstrated statistically significant differences between ball type and both linear acceleration and angular velocity for males (F=35.66; p=<0.001) and females (F=21.04; p=<0.001) for Balls 1-3. Table 3 summarises the data for male and female players combined and separately.

insert table 3 here*

Significant differences by-sex were demonstrated for linear acceleration (p=<0.001) and angular velocity (p=<0.001).

Table 4 shows the percentage difference between linear acceleration and angular velocity for each ball type. The mean linear acceleration of the players' head during heading was 47% lower for Ball 3 when compared with Ball 4. The difference between means (using first Ball 4 as the reference ball followed by Ball 2), were statistically significant for all of the comparison balls regardless of which ball was used as the reference.

insert table 4 here*

The effect of ball and socio-demographic characteristics

For linear head acceleration, 3% of the variance was predicted by age (with older players demonstrating lower peak linear acceleration than younger players), 11% by sex (females demonstrating lower peak linear acceleration than males), 38% by ball pressure (lower ball pressures being associated with lower peak linear acceleration) and 56% by ball mass (lighter balls were associated with lower peak linear acceleration) (see Table 5). For angular velocity, 11% of the variance was predicted by age (older age being associated with lower angular velocity), 23% by sex (females demonstrating lower angular velocity), 10% by the number of headers performed per week (players who headed the ball more often had lower angular velocity), 24% by ball pressure (lower ball pressures were associated with lower angular velocity) and 13% by ball mass (lighter balls were associated with lower angular velocity).

insert table 5 here

Discussion

This study is believed to be the first to explore the effect of different ball types and characteristics on head acceleration during heading in male and female youth football players. Our findings demonstrated that head accelerations for youth players can be reduced by 59% using a lighter size 5 ball (Ball 1-192g), 47% using a lighter size 4 ball (Ball 3- 255g) and 26% using a size 5 ball with reduced ball pressure (Ball 2, 5psi) when compared with a size 5 match-regulated ball (430g; 10.5psi). Lower head accelerations were also observed using a size 4 ball (5psi) when compared to both a low pressure (5psi) size 5 ball and a higher pressure (10.5psi) size 5 match-regulated ball. Multiple regressions supported that lighter balls or balls with lower pressures were associated with lower peak linear acceleration and peak angular velocity.

Earlier studies have explored the relationship between ball properties and head acceleration using mathematical models (Queen et al., 2003, Naunheim et al., 2003a, Tierney et al., 2020), a headform model (Naunheim et al., 2003b, Dunn et al., 2020, Tierney et al., 2020, Cecchi et al., 2020) force plate (Auger et al., 2020) or adult players (Shewchenko et al., 2005). A study by Shewchenko et al.

(2005) was the only known study to evaluate the relationship between head acceleration and ball mass and pressure during heading using 7 active football playing adult participants (as well as numerical modelling). That study reported a 10% reduction in linear head acceleration with a ball pressure reduction of 50%, as well as a 10% reduction in head acceleration with ball mass reductions of 20% (Shewchenko et al., 2005). None of the other studies which explored the relationship between ball size, mass and/or pressure and head acceleration used human participants. Instead, conflicting findings were reported from studies using a mathematical model (Queen et al., 2003, Tierney et al., 2020) or headform model (Dunn et al., 2020, Cecchi et al., 2020, Tierney et al., 2020). Queen et al. (2003) reported that increases in ball size or pressure had little influence on head acceleration. However, the lowest pressure used in their study (10psi) was comparable to the highest pressure used in our size 5 match ball (Ball 4, 10.5psi). It is possible that balls above a certain pressure (such as 10 psi) do not show the same reduction in head acceleration when compared with lower pressure balls (such as the 5psi ball pressure used in our study). Whether a ball pressure threshold exists requires further investigation. A later study which assessed the effect of ball speed, mass and stiffness on the forces experienced during heading using mathematical and human body computational model simulations reported that the force experienced by the head is mainly influenced by the speed of the ball, with higher velocity balls demonstrating higher accelerations (Tierney et al., 2020). Although we did not assess ball speed in our study, a study which used the same ball as our Ball 2 (size 5 Adidas Starlancer) reported that while peak impact force (assessed using a force plate) was influenced by ball velocity, lowering ball inflation pressure provided the greatest return in decreasing peak impact forces (Auger et al., 2020). A decrease in ball pressure from 16psi to 8psi (from the high to low end of the IFAB ball regulations) resulted in a 20% reduction in ball impact force (Auger et al., 2020). Additionally, Dunn et al. (2020) reported that headform impacts with smaller size 4 (370g) balls had lower accelerations when compared with standard (410g) and standard-light (350g) size 5 balls. Finally, another study which used a headform model revealed an increase in peak linear acceleration ($p = 0.001$) and peak rotational acceleration

($p = 0.002$) with higher ball velocities, and a decrease in peak linear acceleration ($p < 0.001$) and peak rotational acceleration ($p < 0.001$) with lower ball pressures (Cecchi et al., 2020).

Consistent with the earlier published literature, our results demonstrated that head acceleration is affected by different ball characteristics such as ball mass and pressure. Our results indicated that when compared to Ball 4, the match-regulated ball, the other 3 balls demonstrated lower head acceleration of between 26-59% in experienced youth football players. This is important to note because many football associations around the world have yet to produce heading guidelines and most of the guidelines that do exist generally only make recommendations regarding the age that players can start to head the ball (Yang and Baugh, 2016, Football Association (England). 2020). US Soccer have prohibited heading in training and games for players 10 years and younger with restricted heading practice until 14 years (Yang and Baugh, 2016). Our results indicated that although older age and female sex were associated with lower head accelerations during heading, there was a stronger relationship between lower head acceleration and lower ball mass and pressure. Changing ball mass and pressure are also easy strategies to implement (Auger et al., 2020). One football association who recently updated their heading guidance is the Football Association in England (Football Association (England). 2020). Their guidelines do not recommend heading in training sessions for players aged under-11 years and younger with restricted heading in training from under-12 to under-18 age groups (Football Association (England). 2020). No restrictions on heading are reported during games. One of the main concerns in allowing heading in games before players have learned this complex skill in training is that young players' first experience of heading may be with a high-pressure regulated match ball from a high-velocity kick rather than from a low-velocity throw-in (Peek et al., 2020c). Even though younger players compete with smaller size 3 (8 years and under) and size 4 (8-12 years) balls, these balls are still recommended to have the same pressure as a size 5 match ball (8.5 to 15.6psi). This means that young players could be heading balls in games with no heading technique training, which potentially exposes them to far higher head accelerations than if they were to head the ball in training using lighter/lower pressure balls.

Learning safe heading technique is not just about mastering the point of head-ball contact but also learning how to time a jump, position the body safely and activate the neck muscles to reduce injury risk and the potential impact of heading on brain health (Peek et al., 2020a, Peek et al., 2020b). It has been reported that heading-related head and neck injuries in football depend more on the acceleration of the head than on the applied force(Mehnert et al., 2005). Increased axial loading of the cervical spine from heading using the top of the head has also been associated with a higher risk of injury(Mehnert et al., 2005). Furthermore, the majority of concussions occur in football due to heading duels where head-head or head-elbow/shoulder impacts occur(Beaudouin et al., 2019a, Beaudouin et al., 2019b). To place restrictions on the ability of young players to develop these highly complex skills under the guidance of their coach in training may ultimately increase players' risk of injury during competition.

A more pragmatic approach to heading is perhaps the one adopted by UEFA where heading is allowed in training for all ages with unnecessary heading drills (such as head tennis) strongly discouraged as well as using the appropriate ball size for each playing age-group at the lowest pressure authorised by the IFAB 'Laws of the Game'(Union of European Football Associations, 2020). This does not mean that heading practice should start in very young players or with high practice burden but does allow coaches to practice heading with players using light weight and/or low pressure balls to master technique before they start to head higher pressure match balls in games, which for some players is around 9 to 11 years of age(Beaudouin et al., 2020, Salinas et al., 2009).

Females in our study demonstrated lower head accelerations than male players ($p=<0.001$). This is contrary to previously published research which has consistently shown that females have higher head accelerations during heading than males(Peek et al., 2020b). Although we did not objectively measure outcomes for heading technique, it was subjectively noted that there were marked differences in the way males and females headed the ball in our study, particularly their starting standing position (which we did not control for except to ensure that players' feet remained grounded). Male players tended to adopt a standing position with one foot placed in front of the other whereas females tended to position themselves more square to the ball. This meant that male players usually demonstrated a weight shift from their back foot to their front foot to meet the ball, whereas females tended to remain more stationary and wait for the ball to come to them. This increased movement of the male players may have resulted in higher accelerations being recorded by the accelerometer. One recommendation for future research is to analyse variations in heading technique between males and females as well as different age groups of players and at different ball speeds (with higher speed balls, the heading technique adopted by many females may demonstrate different head acceleration results). This analysis could be performed using video or optoelectronic analysis as well as placing additional markers and accelerometers on the players so head acceleration in relation to trunk movement could be further explored to account for any changes in weight shift.

Strengths and limitations

The strength of this novel study was the use of an accepted game scenario (i.e. controlling a throw-in by heading the ball) for the players to replicate. We also used a far greater sample size of players (n=61) than previous research using a sample size of 7 adult football players (Shewchenko et al., 2005), or headform models (Naunheim et al., 2003b).

There were also several limitations which should be acknowledged. Firstly, earlier research has indicated that head mounted sensors may over-estimate peak acceleration during heading due to poor coupling when compared with mouthguard sensors under laboratory conditions(Wu et al., 2016). Pilot testing of our measures revealed no detectable slippage and good coupling of the ‘swim cap’ during heading on video analysis. However, it is acknowledged that our data may be over-estimated for all 4 balls but that this should not impact on the interpretation of the results as each ball and header were subject to the same conditions.

A small number of head acceleration data exceeded the limits of the accelerometer, meaning that these data could not be used. Although this only affected 2% of the total number of recorded headers, the majority were seen with Ball 4 - the match ball. This possibly indicates that an accelerometer with a higher upper limit would be needed to record head accelerations from balls with greater pressure or delivered at speeds higher than the throw-ins used in this study. It also means that our comparison data between balls may be under-estimated as the highest head accelerations with Ball 4 were not recorded. Additionally, the head accelerations for Ball 4 are only representative of male players as no females headed this ball which is also likely to have impacted on our results. The placement of the motion sensor on the occiput rather than the centre of mass of the head may also limit the interpretation of results. The occiput was chosen as it was an easy anatomical marker to locate quickly between players. Additionally, all participants played for one club which might limit the generalisability of the results to other populations. A final limitation is that we did not capture heading technique or record ball speed following the header. These would make interesting additions to future studies to explore whether heading performance outcomes are affected by ball characteristics, sex, age and technique.

Conclusion

Given the conflicting evidence whether frequent heading of the ball is associated with long term issues with brain health, it is prudent to explore strategies which can minimise the potential harm to players(Peek et al., 2020a). This study provides evidence that reducing ball pressure, ball size and/or ball mass can have an effect on reducing head accelerations in youth players. Changing ball characteristics, particularly in training when heading is practiced, is an easy strategy to implement but may require top down support from football organisations to increase buy-in from players and coaches.

Practical implications:

To reduce head acceleration during heading, it is recommended that football organisations and coaches consider ball size, mass and pressure and only use balls which are appropriate for each playing age-group (a strategy which is easy to implement from a regulatory perspective).

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Table 1: Summary of ball characteristics

Ball number	**Brand**	**Size**	**Mass (g)**	**Pressure (psi)**
1	KickerBall™	5	192	5.00
2	Adidas Starlancer™	5	432	5.00
3	Heading-Pro™	4	255	5.00
4	Deploy Envision™	5	430	10.50

Key: g=grams; psi=pounds per square inch

Figure 1: An example of the accelerometer trace for resultant linear acceleration (g) during purposeful heading for one player (demonstrating 3 headers per Ball type 1-4)

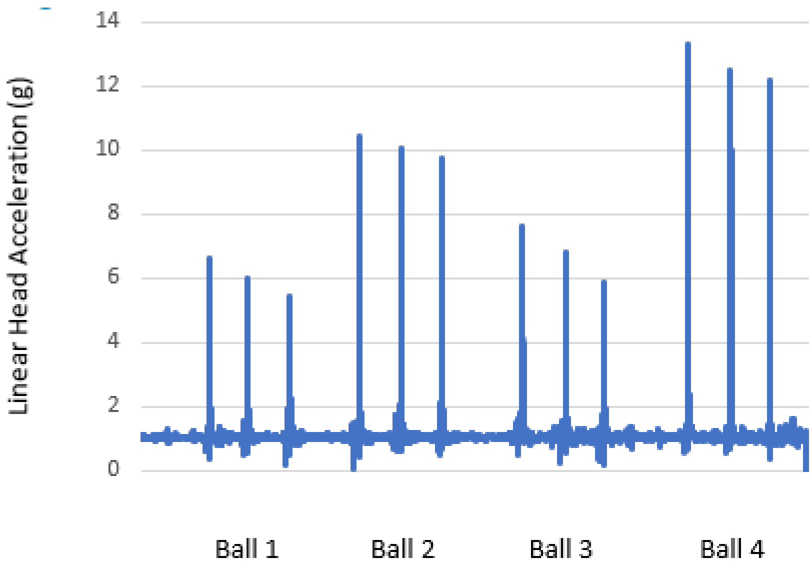

Table 2: Player characteristics (mean, standard deviation (SD), range) for age, height, weight, playing experience, training volume and self-reported number of headers per week for males and females and combined data.

Sex (n)	**Age (yrs)**	**Height (m)**	**Body mass (kg)**	**Playing experience (yrs)**	**Training volume per week (hrs)**	**Headers performed per week (n)**
Combined	14.52	1.66	54.26	8.86	5.31	8.07
(n=61)	(1.37)	(0.09)	(9.42)	(1.96)	(1.97)	(8.99)
	12-17	1.49-1.88	37-77	3-13	3.5-16	0-35
Male	14.51	1.69	55.77	8.97	5.56	10.34
(n=35)	(1.20)	(0.09)	(9.69)	(1.94)	(2.24)	(10.72)
	12-16	1.52-1.88	37-75	3-12	4-16	0-35
Female	14.63	1.63	52.59	8.73	4.98	5.00
(n=26)	(1.66)	(0.06)	(9.05)	(2.05)	(1.52)	(4.88)
	12-17	1.49-1.72	37-77	4-13	3.5-9	0-20

Key: yrs=years, m=metres, kg=kilograms, hrs (hours)

Table 3: Summary of linear acceleration and angular velocity data during purposeful heading for male and female players as well as combined data.

Ball	Participants (n=)	Linear acceleration (g)			Angular velocity (rad/s)		
Combined male and female players:							
		Min	**Max**	**Mean (95%CI)**	**Min**	**Max**	**Mean (95%CI)**
1	61	3.75	9.88	6.34 (5.98-6.70)	1.37	11.48	5.00 (4.28-5.71)
2	61	5.78	16.51	11.37 (10.76-11.97)	1.27	16.64	6.91 (5.97-7.85)
3	51	4.39	12.34	8.12 (7.56-8.67)	1.42	11.37	5.93 (5.13-6.72)
4	25	9.54	21.51	15.44 (14.42-16.46)	5.42	16.79	11.64 (10.33-12.95)
Male players only:							
Ball	**Participants (n=)**	**Linear acceleration (g)**			**Angular velocity (rad/s)**		
		Min	**Max**	**Mean (95%CI)**	**Min**	**Max**	**Mean (95%CI)**
1	35	4.90	9.61	6.55 (6.16-6.93)	1.37	10.65	5.75 (273-386)
2	35	7.48	16.50	11.70 (10.77-12.62)	5.36	11.37	8.28 (7.47-9.09)
3	25	6.48	12.34	8.84 (8.11-9.57)	1.27	16.63	7.50 (6.02-9.08)
4	25	9.54	21.51	15.44 (14.64-16.24)	5.42	16.79	11.64 (10.61-12.67)
Female players only:							
Ball	**Participants (n=)**	**Linear acceleration (g)**			**Angular velocity (rad/s)**		
		Min	**Max**	**Mean (95%CI)**	**Min**	**Max**	**Mean (95%CI)**
1	26	3.75	8.21	5.53 (5.07-5.98)	1.54	7.06	3.22 (2.62-3.80)
2	26	5.78	15.87	10.54 (9.57-11.51)	1.98	10.21	5.42 (4.45-6.41)
3	26	4.39	10.59	4.39 (3.75-5.03)	1.42	8.40	3.93 (3.18-4.68)
4	-	-	-	-	-	-	-

Table 4: Summary of changes in linear acceleration and angular velocity for each ball type compared with reference Ball 4 and reference Ball 2 (T-test).

	Reference Ball 4		**Reference Ball 2**	
Ball	**Linear**	**Angular**	**Linear**	**Angular**
1	59%↓*	57%↓*	44%↓*	28%↓*
2	26%↓*	41%↓*	**ref**	**ref**
3	47%↓*	49%↓*	29%↓*	14%↓**
4	**ref**	**ref**	36%↑*	69%↑*

*p=<0.01; **p=<0.05; ↓ lower compared with reference ball; ↑ higher compared with reference ball

Table 5: Summary of predictors for linear acceleration and angular velocity (regression analyses).

Variable	**Linear acceleration (g)**			**Angular velocity (rad/s)**		
	R^2	**F**	**p-value**	**R^2**	**F**	**p-value**
Age	0.03	6.31	0.01*	0.11	21.63	<0.001*
Sex	0.11	1.71	<0.05*	0.23	49.47	<0.001*
Headers performed per week	0.01	0.19	0.19	0.10	20.53	<0.001*
Ball pressure	0.38	103.55	<0.001*	0.24	54.53	<0.001*
Ball size	0.003	0.57	0.45	0.01	1.70	0.20
Ball mass	0.56	217.93	<0.001*	0.13	24.40	<0.001*

*Statistically significant