Review articles

Narrative Literature Review on Head Injury and Heading in Women's Football and Investigating any Association with Menstrual Cycle

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As part of a broader FIFA initiative to guide research in women's football, this review sought to synthesize existing literature across all levels of competitive play, with the objective of assessing the current scope and depth of research focused on head injuries and heading in the women's game. The study reviewed available literature on head injury, heading in women's football and its association with menstrual cycle phase, published by an updated search performed in October 2023

Head Injury in Women's Football

Although women's football has seen significant growth in both popularity and participation, research into the injuries sustained by female players remains notably limited. Head injuries in female football players have been a major concern, and head injury incidence may be considered worrying owing to the possibility of both acute and long-term structural and functional alterations in the brain.

Through reviewing existing literature, head injuries represent a significant proportion of the types of injuries sustained by female football players. In this meta-analysis, head and neck injuries were shown to be the third most injured region (0.3 per 1000 hours of exposure, 95% CI) [1]. Figures may be even higher as head and neck injuries are frequently underdiagnosed due to their symptoms and reporting. Another survey analyzed the incidence, nature, and context of injuries among elite female footballers participating in top-tier international tournaments, revealing that 84% of these injuries resulted from player-to-player contact. Of these, the majority involved the lower extremity at 65%, followed by head and neck injuries at 18% [2]. In the existing literature, an increased concussion risk amongst female players has been identified. Data from several FIFA tournaments indicate that concussions comprised 22% of head and neck injuries among female players, compared to just 8% among their male counterparts. When considering concussion alone, the incidence rate was 2.6 per 1,000 player hours for women, notably higher than the 1.1 per 1,000 player hours observed in men, reflecting a 2.4-fold increased risk in female athletes. Supporting this trend, another study reported a higher susceptibility to concussion among female players in both football and ice hockey compared to males.

Studies indicate a higher rate of concussion in female football players compared to their male counterparts. A systematic review and meta-analysis of epidemiological data on injury patterns in women's football reported an overall injury incidence of 6.1 per 1,000 hours of exposure, higher than that observed in men. Furthermore, a six-year prospective case control study analysing head and neck injuries during 20 FIFA tournaments between 1998 and 2004 found an overall incidence of 12.5 injuries per 1,000 player hours—12.8 in men and 11.5 in women. Interestingly, despite the slightly lower injury rate, female players experienced a greater impact on their playing careers, with time loss

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injuries recorded at 4.1 per 1,000 player hours in women compared to 3.5 in men [3].

Different mechanisms of head injury in women's football have been suggested, compared to men's football. Although player to-player contact remains the leading mechanism behind most concussions in both male and female footballers, one study examining concussion rates among female players identified several additional risk factors specifically contributing to head and neck injuries in women This included greater head neck segment peak angular acceleration and displacement in females than in males when heading the ball, lower levels of isometric neck strength, neck girth and head mass—resulting in lower levels of head neck segment stiffness [3].

Another study investigating the biomechanical mechanisms underlying sex-based differences in injury patterns found that, despite earlier activation and greater relative engagement of head–neck musculature, female athletes exhibited significantly higher peak angular acceleration and displacement of the head–neck segment compared to their male counterparts. Player position and free heading were not significant injury mechanisms [4]. A pilot cross-sectional study examining whether the relationship between anthropometric characteristics and heading kinematics differs by sex found that female athletes exhibited significantly lower neck flexor and extensor strength, reduced head mass, and smaller head–neck segment length and girth compared to male athletes. When heading a ball at speeds of 25 mph and 40 mph, women also demonstrated greater linear acceleration and rotational velocity. The study concluded that, relative to men, female players possess lower anthropometric measures and are subjected to increased head impact kinematics during heading [5].

Several mechanisms for increased concussion risk have been suggested. Factors may include differences in head-to-ball ratio in women's football, strength(neck), as well as rules changes [6]. A systematic review on concussion in female athletes to evaluate the potential risk concluded, peak linear acceleration (PLA) and peak rotational acceleration (PRA) are associated with higher concussive impacts for a mean PLA of 98.68g and PRA of 5776.60 rads/s. This demonstrated that female athletes may be more susceptible to concussion, have prolonged symptoms after a concussion, and are more likely to report a concussion than their male counterparts [7]. Further research into biomechanical differences, as well as social and behavioural factors, is necessary to explore this further.

Several studies have identified sex-related differences in neck musculature as a contributing risk factor for concussion among female athletes. Research examining the role of cervical muscles during heading in football has demonstrated that individuals with smaller neck circumference and reduced muscular strength experience higher head acceleration upon impact. These findings may, in part, explain the consistently higher concussion rates observed in women's football compared to other sex comparable sports. Females have lower biomechanical tolerance to head impacts and are shown to activate their sternocleidomastoid muscles earlier in response to impact, resulting in greater peak angular acceleration and displacement [8].

Hormonal differences and their impact on head injury have also been proposed as explanations for differing head injury and concussion risk. Only a single study investigating hormonal influences was found that among concussed female collegiate athletes, menstrual cycle phase at time of injury was not associated with differences in symptom severity or time to recovery [8]. A proposed theory, the 'withdrawal hypothesis' suggests that head trauma sustained during the high-progesterone luteal phase of the menstrual cycle may disrupt hypothalamic and pituitary function, leading to an abrupt decline in progesterone levels. However, current evidence supporting this mechanism in humans remains limited. As such, a more comprehensive understanding of these hormonal influences and their potential role in head injury susceptibility among female footballers is essential for informing effective prevention strategies and protective interventions.

Heading in Women's Football

Heading in football involves the act of using the head to strike the ball during gameplay. It is an important skill that requires various components such as physiological, technical, tactical mental, and physical abilities [9]. The technical skills involved in heading include juggling, speed dribbling, passing, shooting, and heading [10]. Heading in women's football players has been found to have both short term and long-term effects on brain function. Therefore, increased understanding of head impact frequency, magnitude and heading behaviours in women's football may help to inform efforts to prevent brain injury.

A study employing mouthpiece-based sensors to assess the biomechanics and characteristics of head impact exposure in National Collegiate Athletic Association (NCAA) women's soccer players reported a mean head impact rate of 0.468 impacts per hour. Exposure varied depending on the session type and player position. Notably, headers constituted 89% of all head impacts and were associated with significantly greater linear and rotational accelerations compared to non-header impacts. Headers resulting from long kicks demonstrated greater peak kinematic values than those delivered by other methods [11]. This study also identified positional differences in head impact magnitudes, with defenders, forwards, and midfielders experiencing higher mean linear accelerations than goalkeepers. Similarly, rotational accelerations were greater among outfield players compared to goalkeepers. However, given the limited sample size of only 16 female athletes, further research with larger cohorts is necessary to more thoroughly investigate variations in head impact across playing positions.

A cross-sectional study on linear acceleration in direct head contact across impact type, player position, and playing scenario in collegiate women's soccer players using smart monitor accelerometer examined accelerations in different game scenarios. It revealed head-to head impacts (51.26 g ± 36.61 g, n = 13; P < .001) and unintentional deflections (37.40 g ± 34.41 g, n = 24; P = .002) resulted in higher mean linear accelerations than purposeful headers (shots, clears, and passes). No differences were seen in linear acceleration across player position or playing scenario. Given the head impact figures, the study concluded that unintentional and head-to head impacts are major concerns for head injury in women's soccer [12].

Another study demonstrated differences in both the frequency and nature of head impacts between women's and men's football. Men were more likely to sustain head impacts overall (IRR = 1.74, 95% CI: 1.59–1.92). The highest incidence rate for men was head to body contact (IR = 611.68, 95% CI: 553.11–670.25), whereas for women it was ball to head impacts (IR = 302.29, 95% CI: 270.93–333.64). Notably, women experienced the highest frequency of head impacts when heading the ball (IR = 667.23), while men most commonly sustained head to body contact (IR = 611.68 [13]. Female players also sustained ball to head impacts with greater linear and rotational accelerations. Although this study was limited by its sample size, single center design, and instrument sensitivity, it underscores the need for further research to elucidate sex specific differences in head impact characteristics, with particular focus on the heightened linear and rotational forces associated with heading in women.

Variations in anthropometric characteristics have been proposed to account for differences in linear acceleration observed during heading between women's and men's football. Multiple studies have demonstrated that female athletes tend to have shorter neck dimensions, lower head mass, and narrower neck girth, which collectively contribute to reduced neck strength and consequently greater head–neck acceleration upon impact. One investigation assessed the relationship between head and neck size, neck strength, and both linear and rotational acceleration during purposeful soccer heading using triaxial accelerometers and gyroscopes. Through multiple regression analysis, size variables accounted for 22.1% of the variance in peak linear acceleration (PLA) and 23.3% of the variance in peak rotational acceleration (PRA). Strength variables explained 13.3% of the variance in PLA and 17.2% in PRA, while technique variables did

not significantly predict either measure. These results highlight that head and neck anthropometry and muscular strength are significant predictors of both PLA and PRA during heading. Another study revealed similar findings, with female athletes displaying significantly lower neck flexor and extensor strength, smaller head mass, head-neck segment length and girth than male athletes. The results also showed that women generated greater linear acceleration speed and rotational velocity when heading a ball at the speed of 25mph and 40mph. The results from this study suggest that neck girth and neck strength may be a factor in limiting head impact kinematics [14]. Therefore, anthropometric and neck strength measurements should be considered as a preventive measure for head injurie in women's football [15]. Consequently, strength training of the neck musculature may play a role in reducing linear acceleration and rotational velocity thereby reducing sub concussive impact, is an important training consideration. To improve heading performance, it is crucial to have strong neck muscles, specifically the neck extensors and flexors [16]. Research has shown a positive relationship between neck muscle strength and heading performance, with better performance observed when the neck extensors are stronger than the neck flexors [17].

Similarly, heading techniques may influence head impact kinematics, and this also has implications in the provision of the appropriate training among female footballers. A relationship between heading technique and head kinematics in female youth soccer players using instrumented mouthpiece device revealed jumping headers were generally higher magnitude than standing headers. A significant association was observed between technique score and peak linear acceleration of standing headers. Better technique was also associated with lower peak rotational acceleration during games but not practices. Investigation of individual technique criteria suggests back extension and shoulder/hip alignment may be key factors for reducing peak head kinematics relative to other technique criteria [18]. Given the limited sample size of 14 participants, larger-scale studies incorporating more objective evaluations of heading technique are warranted to enhance player safety by mitigating cumulative head acceleration exposure.

Tissue strain resulting from heading represents a critical area of investigation, with variations observed across different player levels and ages. A study employing custom designed mouthpiece sensors to assess head kinematics and brain tissue strain during intentional headers in youth and collegiate female soccer players demonstrated that level of play was significantly associated linear acceleration, rotational acceleration, rotational velocity, principal strain, and area under cumulative strain damage metrics. Collegiate players exhibited notably higher mean values across all these parameters compared to youth players (all $p < 0.001$). These findings emphasize the need for targeted interventions tailored to the level of play to mitigate head impact severity in soccer. Although no concussions were reported in this cohort, ongoing research into brain strain may yield valuable insights into the mechanisms of head injury and the neurological consequences of sub concussive impacts [19].

In terms of neurological effect, one study found that greater 12 month heading exposure was associated with lower rates of learning among women, but not among men [20]. Additionally, a study on female youth soccer players found that cumulative purposeful heading had effects on autonomic nervous system function [21]. The effects of repetitive head impacts associated with soccer heading on balance, neurocognitive function, and head impact biomechanics were examined in another study, which found no significant changes in head impact biomechanics, but observed deficits in balance positions [22]. As football players are regularly exposed to head impacts by intentionally heading the ball, further research is necessary in order to determine the head impact burden of heading in the game.

Heading, Head Injury and Menstrual Cycle

The menstrual cycle is characterized by a sequence of structural and functional modifications driven by hormonal interplay within the hypothalamic pituitary ovarian axis, regulated through intricate hormonal

fluctuations. The primary hormones involved are estrogen and progesterone. Throughout the follicular phase, estrogen levels progressively rise while progesterone remains low. Following ovulation, during the luteal phase, concentrations of both estrogen and progesterone increase. These hormonal fluctuations have been associated with a range of physiological and psychological effects. Estrogen plays a role in muscle strength, power, and endurance. Progesterone affects thermoregulation, coordination, and recovery. Luteinizing hormone and follicle stimulating hormones have potential impact on neuromuscular control. There is an interplay between hormones and other factors affecting sports performance. Subtle disruption of the balance between estradiol and progesterone during the menstrual cycle can affect multiple parameters, ranging from adverse symptoms including pain, fatigue, transient weight gain, sleep disturbance, and mood disorders [23]. Female sex hormones have significant physiological effects, including altering fluid regulation, modifying cardiovascular muscular, thermoregulatory and metabolic responses to different stimuli [24]. Sports performance affected by the menstrual rhythm may include cardiovascular, respiratory, brain function, metabolic parameters and implications for strength and aerobic and anaerobic performance [25].

The menstrual cycle induces a range of physiological and hormonal fluctuations in women that may influence key factors such as reaction time, coordination, and muscle strength. A systematic review examining the effects of physiological and psychological variables across at least one phase of the menstrual cycle in elite athletes revealed inconsistent associations with several performance-related outcomes, including endurance, power, resistance, ligament stiffness, decision making, psychological state, and competitiveness. Symptoms such as fluid retention, weight gain, mood disturbances, and dysmenorrhea were linked to declines in performance and physical capacity among female soccer players. Additionally, sleep deprivation may impair cognitive function, adversely affecting attention and decision making during subsequent training sessions, thereby potentially increasing injury risk.

Although some research has explored the impact of menstrual phases on athletic performance and injury risk, the relationship between menstrual cycle phases and head injuries in soccer remains complex and incompletely understood. The recent surge in female athletic participation has been accompanied by a corresponding rise in injury incidence. Despite this, female athletes have often been underrepresented in research, with many studies excluding them due to concerns about hormonal fluctuations related to the menstrual cycle and their potential effect on injury risk. Notably, women are estimated to be approximately five times more likely than men to sustain anterior cruciate ligament (ACL) injuries [26]. However, the precise role of hormonal factors in influencing sports related injuries has yet to be fully elucidated.

A cohort study investigating the influence of menstrual cycle phase and prolonged cycle length on injury incidence among international footballers found that injury rates were 47% higher during the late follicular phase compared to the early follicular phase, while rates were 24% lower in the luteal phase relative to the late follicular phase. Notably, muscle and tendon injuries were 88% more frequent during the late follicular phase compared to the early follicular phase. Furthermore, a relatively large proportion of all injuries (20%) occurred after the expected date of menstruation [27]. Though this was a self-reported outcome and blood samples were taken, the findings are significant and should be investigated with head injury association in football with the nature of the heading impacts.

A systematic review examining the relationship between the menstrual cycle and injury risk in female athletes identified the ovulatory phase as a period of heightened vulnerability. This phase is characterized by increased ligamentous laxity, driven in part by peak oestradiol levels, which are associated with reduced strength and impaired neuromuscular control. Consequently, the ovulatory phase corresponds with an elevated risk of injury. Additionally, elevated

levels of the hormone relaxin during the follicular and luteal phases have been linked to anterior cruciate ligament (ACL) injuries. While increased ligament laxity appears to correlate with cyclical rises in body temperature given that heat enhances tissue elasticity this causal relationship remains unproven [28].

A study to evaluate generalized ligament laxity in the late follicular and ovulatory phase of menstrual cycle found, knee recurvatum and generalized ligament laxity were higher in the ovulatory phase than in the late follicular phase. Variations in E2 concentration during the menstrual cycle may thus affect variations in generalized laxity. Generalized ligament laxity was significantly higher in the ovulatory phase than in the late follicular phase, suggesting that the soft tissues around the joints may have changed with menstrual cycle, predicting that hormonal fluctuations may affect joint laxity [29]. This was a small study population of 15 university girls, clinical significance was not studied in neck ligament laxity and further needs to be investigated among women football players in the future. Prospective longitudinal studies on neck ligament laxity within menstrual cycle in women's football is warranted.

Although various hypotheses have been proposed linking menstrual cycle phases to heightened concussion risk, current evidence remains limited. A prospective cross sectional cohort study investigating "preliminary evidence for a window of increased vulnerability to sustain a concussion in female athletes" tracked concussion incidence across menstrual phases in collegiate female athletes. The findings identified a distinct 9-day period of increased susceptibility to concussion during the late luteal phase and the initial days of menstruation. This risk may be associated with declining or low concentrations of estrogen and progesterone that could be speculated to reduce neuroprotection, and perhaps, blunt the recovery time from symptoms [30]. This was a small study, not restricted to football. Normal cycle assumed to be 28 days and stages of cycle presumed standard with no blood samples taken. Therefore, more comprehensive study is needed.

Most studies examining the menstrual cycle in relation to injuries have focused primarily on the association between concussion and symptomatology or outcome prediction, rather than considering the menstrual cycle as a direct causative factor in head injury. One study investigating the relationship between concussion and abnormal menstrual patterns in adolescents found an increased risk of multiple menstrual irregularities following concussion. Given the potential health implications of such disturbances, close monitoring of menstrual patterns post-concussion is advisable in this population [31]. Further research is essential to clarify the long-term effects of concussion on the hypothalamic pituitary ovarian axis and its functional integrity.

Phases of the menstrual cycle may also influence the psychological state of female football players. A preliminary study examining the impact of the menstrual cycle on training and performance in elite athletes explored how different phases affect performance and decision making. It found that physiological performance was significantly better during the menses phase (MP) compared to the proliferative and secretory phases (PSP). Individual responses varied, but athletes using oral contraceptives exhibited greater performance fluctuations between MP and PSP, suggesting that oral contraceptives may negatively affect performance in some individuals. Decision making, assessed using the Cambridge Gambling Task (CGT), revealed that impulsivity was significantly influenced by menstrual phase, with increased impulsivity during MP compared to PSP, while risk taking, error rates, and response times remained unaffected [32]. Hormonal changes during the menstrual cycle, particularly elevated progesterone levels in the luteal phase, may also affect cognitive function and mood, with some women experiencing irritability or mood swings. These mood fluctuations could potentially impact behavior and motor control, including head movements and heading technique. Currently, there is no literature available addressing these specific associations.

Therefore, the direct link between menstrual cycle phase and head injury risk in soccer is not established. Hormonal fluctuations during the menstrual cycle may alter laxity, strength, body temperature, and neuromuscular control, among others. However, the impact on injury incidence might involve a multitude of other factors, including playing style, skill level, protective equipment, and the nature of the sport itself. Women constantly adapt to hormonal variations, which limited current literature indicates exposes them to a higher risk of injury [33]. Hormone relaxin, estrogen, and progesterone concentrations are regulated, so it is also important to investigate the effect of hormonal contraceptives in relation to sports injuries. There were no established studies investigating various menstrual cycle phase as an associated factor for head injury in women's football. Longitudinal prospective studies with large number of athletes need to be included for this survey.

Conclusion

The observed disparity in head injury rates between female and male soccer players likely arises from an interplay of biomechanical, neuromuscular, and hormonal factors that collectively compromise the female athlete's capacity to mitigate head accelerations during impact. Females generally exhibit lower neck muscle strength and reduced neck girth compared to males, limiting their ability to stabilize the head effectively and resulting in increased angular and linear accelerations upon collision. Additionally, sex-specific hormonal fluctuations, particularly variations in estrogen and progesterone throughout the menstrual cycle, influence ligamentous laxity and neuromuscular control, potentially exacerbating vulnerability to head trauma during certain phases. Furthermore, differences in gameplay dynamics, including style of play and frequency of heading, may further elevate injury risk in female players. Taken together, these factors suggest a multifaceted mechanism underpinning the increased susceptibility to concussions and head injuries in female soccer athletes. This hypothesis underscores the critical need for targeted research focusing on sex-specific protective strategies, including neuromuscular training and hormonal considerations, to reduce head injury incidence in women's football.

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