

SEX-RELATED VARIATIONS IN HEAD IMPACT KINEMATICS DURING CONTROLLED SOCCER HEADING

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INTRODUCTION

In the context of sport-related concussions (SRC), soccer, which is one of the female-male comparable impact sports with high head impact rates, significantly contributes to the increasing incidents of SRC. Epidemiological evidence shows higher rates of SRC, longer recovery periods, and more severe post-concussive symptoms among females compared to males in comparable sports such as soccer [1, 2]; however, literature predominantly has focused on male athletes, creating a data gap in sport-related head impacts in females. Moreover, previous studies indicated that the risk and severity of brain damage are correlated with the severity of head impact kinematics and their characteristics such as magnitudes and directions of linear and angular accelerations, angular velocities and impact durations [3]. Despite these findings, there is limited research on the differences in head kinematics characteristics between male and female soccer athletes heading and their potential contributions to the rate of SRC. Therefore, this study aims to explore these differences and examine the role of head mass and impact location in these distinctions using a controlled laboratory experimental setup. The outcome of this study may inform sex-specific SRC prevention and protective strategies in soccer.

METHODS

Thirty-four healthy collegiate soccer players (18 females, 16 males) with an average of 8.2 years of soccer experience participated in this study. The head masses of participants were estimated as a percentage of their body weight (8.26% for males and 8.2% for females [4]). Participants underwent a soccer heading protocol, executing ten frontal head impacts, one minute apart, which is common in soccer heading practice, with a ball launched at 25 mph from 40 feet away [5]. The head kinematics during heading, including x-y-z direction (frontal-sagittal-transverse plane normal direction) and resultant peak angular accelerations (PAA), peak angular velocities (PAV), and peak linear accelerations (PLA), were accurately measured using validated sensor-embedded mouthguards (Prevent Biometrics, MN). Recorded video was utilized to confirm true impacts and identify the location of impacts on

the head, including the front high and top front. Due to the frontal soccer heading protocol, the y-direction and resultant of peak angular accelerations and velocities (PAA-y, PAA-R, PAV-y, PAV-R) and resultant and x-z-direction of peak linear accelerations (PLA-x, PLA-z, PLA-R) were selected for further analyses. The effect of sex and head location of impacts on the kinematics parameters were analyzed using Multivariate Analysis of Variance (MANOVA). The sex, location and their interaction (sex*location) were considered as the main effects in full factorial MANOVA analysis with and without the head mass as a covariate to investigate its effect on the head kinematics. Additionally, pairwise comparison was implemented to explore the effect of the sex factor on each specific level of the location factor. Significance level: 0.05.

RESULTS

Peak Angular Accelerations: Sex had a significant effect on head peak angular accelerations (PAA-y and PAA-R), with greater magnitudes in females, especially for top front locations (Table 1, Figure 1a). However, this effect became insignificant when considering head mass as the covariate. Significant and marginally significant (p-value <0.1) effects of head mass were observed on PAA-R and PAA-y, respectively, in analysis with head mass as the covariate. While the location of impact did not significantly affect PAA-y and PAA-R in both MANOVA analyses, the interaction term (sex*location) showed a significant effect (Table 1).

Peak Angular Velocities: Head peak angular velocities (PAV-y and PAV-R) were not influenced by sex, but were significantly affected by impact location, with a higher magnitude for front high location regardless of adjusting for the head mass as a covariate (Table 1). Also, the interaction of sex and location factors showed a significant effect on PAV-y and a marginally significant effect on PAV-R (Table 1).

Peak Linear Accelerations: Sex did not significantly influence peak linear accelerations (PLA-x, PLA-z, PLA-R) in both MANOVA analyses; however, by including head mass as a covariate, a significant effect of head mass was observed on all three peak linear acceleration

parameters (Table 1, Figure 3a). Also, location and sex*location interaction terms significantly influenced PLA-x and PLA-z, and had no significant influence on PLA-R (Table 1), with or without the head mass as the covariate.

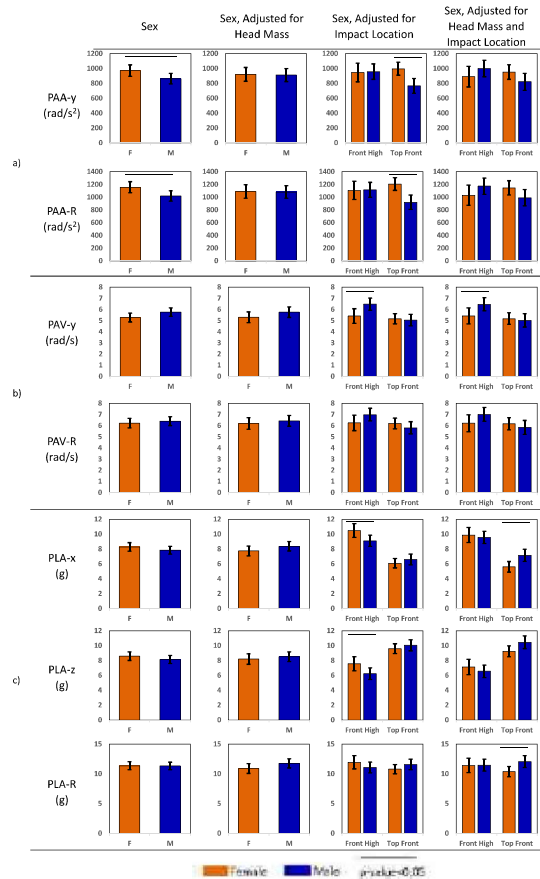


Figure 1: Mean and standard deviation of head kinematic parameters including a) PAA-y and PAA-R, b) PAV-y and PAV-R, and c) PLA-x, PLA-z and PLA-R. MANOVA results with (columns 2 and 4) and without (columns 1 and 3) adjustment for the head mass (as the covariate) are included.

Table 1: Comparison results (p-values) for all head kinematic parameters considering factors including sex, location, and their interactions with (b) and without (a) the head mass as a covariate

		parameter		PAA-y	PAA-R	PAV-y	PAV-R	PLA-x	PLA-z	PLA-R
a) Univariate tests without the head mass as covariate	Factors	Sex		0.04	0.02	0.09	0.54	0.27	0.27	0.92
		Location		0.19	0.44	0.00	0.04	0.00	0.00	0.47
		Sex*Location		0.02	0.02	0.03	0.06	0.02	0.03	0.08
	Pairwise Comparison	Sex comparison (adjusted location)	Front high	0.88	0.92	0.01	0.10	0.02	0.03	0.23
			Top front	0.00	0.00	0.73	0.30	0.31	0.37	0.20
	b) Univariate tests with the head mass as covariate (Adjusted for the head mass)	Factors	Head mass		0.06	0.03	0.93	0.86	0.01	0.05
Sex			0.89	0.93	0.25	0.57	0.25	0.57	0.19	
Location			0.28	0.59	0.00	0.04	0.00	0.00	0.62	
Sex*Location			0.02	0.02	0.03	0.05	0.02	0.03	0.08	
Pairwise Comparison		Sex comparison (adjusted location)	Front high	0.25	0.20	0.04	0.14	0.65	0.42	0.95
			Top front	0.12	0.11	0.74	0.47	0.01	0.06	0.02

DISCUSSION

Peak Angular Accelerations: The effect of sex on peak angular accelerations (PAAs) in soccer heading remains a subject of debate in

the literature due to variations in the accuracy of head kinematic measuring systems and experimental set-ups employed. While some studies have reported that sex does not significantly affect PAAs [6], the majority of research, including our own, has observed significantly higher PAAs in females compared to males in soccer heading [7, 8]. This observation underscores the role of sex as a determinant in the brain injury outcomes of soccer heading, given the consistent reports of a strong correlation between PAAs and brain tissue deformations, as well as brain pathology [3]. This finding aligns with epidemiological studies indicating a greater incidence of concussions in high school and collegiate female soccer athletes compared to their male counterparts [9, 10]. Our results also indicated that the significant impact of sex on PAAs diminishes when accounting for head mass as a covariate, suggesting head mass serves as a mediating factor. This could explain why females, who typically have lower head mass, experience higher PAAs. This aligns with the previous studies that demonstrated head mass not only exhibits a significant adverse correlation with the peak angular and linear accelerations but also varies between sexes [7, 11].

Peak Angular Velocities: This study investigate PAVs of the head during soccer heading, a crucial parameter that is lacking in the literature and is highly correlated with the severity of brain injury [3]. No significant effect of sex and head mass was observed on PAVs. Logically, head mass primarily influences the rate of velocity change (accelerations); explaining why a significant effect of head mass was observed on PAAs and PLAs but not PAVs. Additionally, the higher PAVs for front-high impacts compared to top-front impacts may be attributed to the shorter moment arm in front-high head impacts.

Peak Linear Accelerations: Similar to PAAs and due to different experimental setups and sensor accuracy, literature regarding the effect of sex on the PLAs is inconsistent. While some studies suggested females may experience higher PLAs [8], our findings are in line with the majority of studies that reported no significant effect of sex on PLAs [6, 12, 13]. The significant effect of head mass on PLA parameters aligns with Newton's second law and is in agreement with the literature.

Conclusion: Our findings, showing that females experience higher PAAs, possibly due to their lower head mass, align with epidemiological evidence indicating a greater rate of SRC among female soccer players than males. Future research could investigate other factors such as hormonal dynamic, brain structure, neck stiffness, and heading techniques that contributes to the sex-based variations in the vulnerability, rate, and outcomes of SRC and identify potential interventions to reduce PAAs in female players, such as adjusting ball pressure, employing headgears, and enhancing heading techniques.

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