[Athletic Training]

Sex Differences in Anthropometrics and Heading Kinematics Among Division I Soccer Athletes: A Pilot Study

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Background: Soccer players head the ball repetitively throughout their careers; this is also a potential mechanism for a concussion. Although not all soccer headers result in a concussion, these subconcussive impacts may impart acceleration, deceleration, and rotational forces on the brain, leaving structural and functional deficits. Stronger neck musculature may reduce head-neck segment kinematics.

Hypothesis: The relationship between anthropometrics and soccer heading kinematics will not differ between sexes. The relationship between anthropometrics and soccer heading kinematics will not differ between ball speeds.

Study Design: Pilot, cross-sectional design.

Level of Evidence: Level 3.

Methods: Division I soccer athletes (5 male, 8 female) were assessed for head-neck anthropometric and neck strength measurements in 6 directions (ie, flexion, extension, right and left lateral flexions and rotations). Participants headed the ball 10 times (25 or 40 mph) while wearing an accelerometer secured to their head. Kinematic measurements (ie, linear acceleration and rotational velocity) were recorded at 2 ball speeds.

Results: Sex differences were observed in neck girth ($t = 5.09$, $P < 0.001$), flexor and left lateral flexor strength ($t = 3.006$, $P = 0.012$ and $t = 4.182$, $P = 0.002$, respectively), and rotational velocity at both speeds ($t = -2.628$, $P = 0.024$ and $t = -2.227$, $P = 0.048$). Neck girth had negative correlations with both linear acceleration ($r = -0.599$, $P = 0.031$) and rotational velocity at both speeds ($r = -0.551$, $P = 0.012$ and $r = -0.652$, $P = 0.016$). Also, stronger muscle groups had lower linear accelerations at both speeds ($P < 0.05$).

Conclusion: There was a significant relationship between anthropometrics and soccer heading kinematics for sex and ball speeds.

Clinical Relevance: Neck girth and neck strength are factors that may limit head impact kinematics.

Keywords: biomechanics; head injuries/concussion; neck strength; cervical musculature

A National Collegiate Athletic Association (NCAA) Injury Surveillance System (ISS) study from 1988-1989 to 2002-2003 indicated that concussions were responsible for a high percentage of total injuries in soccer, with women (8.6%) enduring concussions more frequently than men (5.8%).[2,11] Because soccer athletes are subject to cumulative concussive impacts throughout their careers,[17] this could have a negative impact to their quality of life.

Concussive injury in soccer occurs from many mechanisms, where ball-to-head contact causes 8% to 18% of concussive diagnoses.[2,11] Heading is inherent in soccer, with amateur soccer athletes self-reporting between 276 and 1096 headers per year.[17]

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During a header, a player may sustain an impact that results in acceleration, deceleration, and rotational forces on the brain.[26] Likewise, the mechanism of concussion is likely a direct or indirect head impact causing acceleration of the head-neck segment.[23] Therefore, headers may result in a concussion.

Poor attention, memory performance, and verbal learning scores may occur after subconcussive impacts, and have been attributed to damage in the white matter in the brain.[5,6,22,27] This structural damage has been present in some athletes competing in contact sports.[22] Deficits are 3 times greater in athletes enduring repetitive impacts.[5] Greater heading exposure produced greater differences in white matter, specifically in participants with the highest peak rotational acceleration.[22]

Structural and functional deficits may be a result of impacts causing acceleration and deceleration forces on the head,[6] which may be influenced by anthropometric measures, including head-neck segment mass, head-neck segment stiffness, and neck strength. These anatomical and biomechanical differences may contribute to differences in acceleration and displacements after head impact in athletic populations, including soccer heading.[12,15,31]

Researchers have identified a relationship between isometric neck strength and head impact kinematics; strength correlated with decreased head acceleration.[12,15,30-32] Additionally, larger strength differences between flexor and extensor groups during soccer heading resulted in increased head accelerations.[10] These relationships have been used in developing resistance training protocols to combat head accelerations. Unfortunately, there have been no reductions in head impact kinematics after resistance training programs.[18,20]

Female athletes experience a higher incidence of concussion in soccer.[2,5,11] After a head impact, female athletes have exhibited greater linear acceleration, angular acceleration, and angular displacement.[30,31] These impact kinematics may be related to differences in anthropometric measures; female soccer athletes have 50% to 53% less isometric strength of the flexors and extensors, respectively.[30] Differences in head-neck segment length, head-neck segment mass, and neck girth are apparent between sexes.[20,30]

Research has focused on contact sport athletes,[12,18,20,24,25,32] physically active participants,[31] or adolescent athletes.[15,24,25] Attention has focused on the flexor and extensor groups as the sternocleidomastoid activates prior to impacts and the upper trapezius muscle remains active after head impact.[4] Furthermore, the strength of each cervical muscle group has not been evaluated against kinematic measures during soccer heading.[10,18,20,30,31] Therefore, the aim of this study was to evaluate the relationships between anthropometrics and soccer heading kinematics at 2 ball speeds, with an emphasis on differences between male and female collegiate soccer athletes.

METHODS

Participants

All participants read and signed informed consent forms prior to data collection. Temple University's institutional review board approved this study.

Thirteen NCAA Division I soccer athletes (8 female and 5 male) with at least 5 years of heading experience were recruited. Participants were excluded if they suffered a head or neck injury 6 months prior to data collection.

Procedures

The Head Impact Response Questionnaire (Appendix 1, http://journals.sagepub.com/doi/suppl/10.1177/1941738116678615) was used to gather demographic information, obtain history about previous concussions and head impacts, and to collect signs and symptoms that may result from a head impact.[21] Participant height, weight, head-neck segment length, head-neck segment mass, and neck girth were recorded. Participant height, head-neck segment length, and neck girth were measured in centimeters using a tape measure (Medco Sports Medicine). Head-neck segment mass was found using the following equation:

$$\text{Head-neck segment mass} = \text{gender coefficient} \times \text{total body mass}$$

The gender coefficient for male athletes is 8.26% and for female athletes is 8.20%.[29]

Isometric head-neck segment strength was measured using the Microfet Hand-Held Dynamometer (Hoggan Health Industries, Inc) for flexion, extension, right and left lateral flexion, and right and left rotation. This study replicated protocols used in previous studies for measuring head-neck segment isometric strength.[20,25] Each participant was instructed to perform 3 gradual maximal contractions against the stationary handheld dynamometer for 3 seconds during each trial in each direction. The averages of the 3 contractions were used as the criterion value.

A JUGS machine (JUGS Sports International) was used to simulate a soccer kick to each participant. The speed can be adjusted with a dual dial, which was used to replicate 2 speeds of soccer kicks. A size 5, 450-g soccer ball was inflated to 8 pounds per square inch and was fed through the machine at 2 speeds, 25 and 40 mph. The real-time speed that a ball travels during a game is unknown. There are studies that have estimated kicked ball speed (26.5 m/s, 88.5 km/h, equaling around 54.9-59.3 mph) and other variables (ie, footwear, trunk kinematics, effects of fatigue).[9,13,33] Athletes are probably receiving balls at both low and high velocities, resulting from different factors of the game such as a throw-ins, punts, or kicks.

Each participant performed 5 headers at each speed over a 10-minute period, with 1-minute rest between headers. Head impact kinematic measurements were recorded with an accelerometer (Gforcetracker Inc). Measures included peak linear acceleration and peak rotational velocity. Prior to test sessions, sensors were calibrated according to the manufacturer guidelines. During testing, sensors were positioned on the back of the participants' head using prewrap and tape. Impacts measuring <10 g were not recorded.

Data Analysis

Data were analyzed using descriptive and interferential statistics. Independent samples *t* tests were used to identify differences in

Table 1. Means (M) and standard deviations (SD) for anthropometrics

	Men		Women		Total		*P* Value
	M	SD	M	SD	M	SD	
Age, y	19.20	±1.09	20.25	±0.70	19.80	±0.94	0.058
Height, cm	177.40	±8.79	158.73	±36.12	165.91	±29.60	0.288
Weight, kg	70.45	±3.96	66.98	±5.25	63.32	±4.94	0.234
NG, cm	35.90	±1.63	32.35	±0.97	33.65	±2.20	0.000*
HNSL, cm	22.20	±6.58	23.52	±1.14	23.01	±3.95	0.580
HNSM, kg	5.81	±0.32	5.35	±0.42	5.53	±0.43	0.062

HNSL, head-neck segment length; HNSM, head neck segment mass; NG, neck girth.
*Denotes significance ($P < 0.05$).

Table 2. Means (M) and standard deviations (SD) for muscle group strength

	Men		Women		Total		*P* Value
	M	SD	M	SD	M	SD	
Flex	34.66	±8.60	23.12	±5.38	27.56	±8.70	0.012*
Ext	37.40	±8.94	30.20	±7.53	32.97	±8.54	0.147
RLF	25.53	±5.39	20.54	±5.76	22.46	±5.95	0.149
LLF	32.26	±4.68	21.66	±4.30	25.74	±6.85	0.002*
RR	22.06	±6.43	17.66	±3.54	29.35	±5.10	0.136
LR	25.26	±5.66	20.16	±3.77	22.12	±5.06	0.075

Ext, extension; Flex, flexion; LLF, left lateral flexion; LR, left rotation; RLF, right lateral flexion; RR, right rotation. All muscle groups were measured using the handheld dynamometer (in kilograms).
*Denotes significance ($P < 0.05$).

anthropometrics, strength groups, and head impact kinematics between the sexes at the 2 different ball speeds. Pearson correlations were used to determine relationships between both anthropometrics and strength groups and head impact kinematics. All analyses were evaluated using SPSS (version 22; SPSS Inc) and a significance level was set at an alpha level of $P \leq 0.05$.

RESULTS

Demographic and anthropometric information is presented in Table 1. The data presented significant differences in muscle groups between male and female athletes (Table 2). Rotational velocity had a statistically significant difference between sexes at both speeds (Table 3).

Significant negative relationships were identified between neck girth and linear acceleration at 25 mph, rotational velocity at 25 mph, and rotational velocity at 40 mph (Table 4). Neck girth and head-neck segment mass each had significant positive relationships with varying strength groups.

Significant negative correlations were found between linear acceleration and varying muscle groups (Table 5). Linear acceleration at 25 mph correlated negatively with flexors, left lateral flexors, and left lateral rotators. Linear acceleration at 40 mph correlated negatively with flexors, right and left lateral flexors, as well as the left lateral rotators.

DISCUSSION

In soccer, redirecting the ball with the head is an innate part of the game. Heading causes linear and angular accelerations that may result in injurious forces on the brain.[28] In early studies, rotational accelerations had a higher incidence of injury caused

Table 3. Means (M) and standard deviations (SD) for kinematics

KM	Men		Women		Total		*P* Value
	M	SD	M	SD	M	SD	
Linear acceleration speed, m/s							
25 mph	14.70	±2.24	17.86	±3.24	16.64	±3.22	0.085
40 mph	19.58	±5.10	24.08	±4.85	22.35	±5.25	0.140
Rotational velocity, rad/s^2							
25 mph	656.56	±258.03	1038.90	±253.63	891.85	±311.77	0.024*
40 mph	774.60	±501.13	1416.13	±507.63	1169.39	±582.71	0.048*

KM, kinematic measure.
*Denotes significance ($P < 0.05$).

Table 4. Pearson correlations for neck girth and kinematics

Kinematic Measure	Pearson Correlation	*P* Value
LA 25 mph	–0.599	0.031*
LA 40 mph	–0.669	0.051
RV 25 mph	–0.551	0.012*
RV 40 mph	–0.652	0.016*

LA, linear acceleration (m/s); RV, rotational velocity (rad/s^2).
*Denotes significance ($P < 0.05$).

Table 5. Pearson correlations for strength and kinematics

	LA 25 mph		LA 40 mph	
	Pearson Correlation	*P* Value	Pearson Correlation	*P* Value
Flexor	–0.677	0.011*	–0.609	0.027*
Extensor	–0.238	0.433	–0.467	0.100
R lat. flexor	–0.389	0.189	–0.558	0.048*
L lat. flexor	–0.598	0.031*	–0.600	0.030*
R rotator	–0.508	0.076	–0.548	0.053
L rotator	–0.588	0.034*	–0.564	0.044*

LA, linear acceleration; R lat. flexor, right lateral flexor; L lat. flexor, left lateral flexors.
*Denotes significance ($P < 0.05$).

by shear stress[30] and have further been reported to cause diffuse axonal injuries, particularly near the brainstem.[7] A focus of previous literature has been on linear acceleration during an impact[15,18,21]; however, research has demonstrated that both linear acceleration and rotational velocity are important predictors of injury.[6,14]

In both high school and collegiate soccer, concussions occur more frequently in female athletes.[2,11,16] Female players displayed significantly lower flexor and extensor strength, smaller head mass, head-neck segment length, and girth than male athletes.[30,31] This neck girth deficit may be explained by smaller cross-sectional area, and fiber sizes and numbers in the cervical spine musculature.[1,3,19]

Musculoskeletal strength of the cervical spine may combat acceleration and deceleration forces during impact.[12,25,31] Our results identified greater head impact kinematics in participants with weaker muscle groups, which may create a smaller effective head mass. A larger effective head mass may be created from co-contractions of each cervical muscle group, thereby creating rigidity between the head, neck, and torso during impact.[4] When applying Newton's second law of motion ($F = ma$), the same amount of force combined with a larger effective head mass should be capable of limiting the resulting acceleration.[8]

The present data suggest that as neck strength increases, neck girth and head-neck segment mass is increased. This relationship is supported in literature, identifying greater cross-sectional area, mean fiber area, and muscle fiber numbers in participants who underwent strength training.[1,3,19] In the present study, muscle strength also had negative correlations with linear acceleration at both speeds, suggesting that as muscular strength increases, resulting acceleration decreases.[10,12,30,31] In women with lower anthropometry measures, greater head impact kinematics were experienced.[30,31] Therefore, larger anthropometry measurements may aid in increasing the effective head mass, resulting in decreased head impact kinematics.

The present data conflict with findings of youth ice hockey athletes using the head impact telemetry system, where no differences in linear or rotational accelerations were identified between strength groups.[25] The conflicting results may be from differences in measurement styles or limited variability between the 3 strength groups. Also, the current study assessed collegiate athletes, whereas Mihalik et al[25] evaluated youth whose strength may not be developed because of age. Last, the anticipation of impact was not incorporated,[25] which has been studied for its relation to head impact kinematics.[24,31] When an oncoming impact is known, an athlete can preactivate musculature to resist against accelerative forces.[24] Men exhibited less angular acceleration when they anticipated an external force,[24,31] suggesting that decreased head impact kinematics may result from precontracting neck musculature. Understanding the role of anthropometric measures and their relationship with head impact kinematics may aid in developing a strengthening program that may limit head accelerations, which could potentially be related to concussion incidence.

The major limitation of this investigation was the sample size. Even though the study was capable of producing significant results, it may not be generalizable to other athletes. Also, strength measures were studied isometrically. During soccer heading, cervical muscle groups are contracting isotonically, which raises questions regarding the relevance to heading a soccer ball. Finally, electromyography data could have determined the extent of the cervical muscle activation at both speeds.

CONCLUSION

Women display lower anthropometry measures compared with men, and experience increased head impact kinematics during soccer heading. These results suggest that neck girth and neck strength may be a factor in limiting head impact kinematics.

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