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Original Article

Soccer heading drills and concussion-related deficits in high school female athletes

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Abstract:
Repetitive head impacts from soccer heading may result in concussions in female athletes. *Problem Statement:* Concussion assessments exist with efforts to limit headers. Heading drills performed in different environments have conflicting results regarding influences on assessments. *Approach:* To evaluate, within an ecological real-setting environment with unpredictable conditions reflective of game situations, a heading drill's effect on the King-Devick (K-D) and Biodex Biosway Balance Assessment (CTSIB-M). Preseason and post-heading metrics were taken for eleven female high school varsity soccer players (16 ± 1.4 years old) using K-D and CTSIB-M. K-D and CTSIB-M tests were repeated following a heading drill (HD). The number of headers and acceleration data during HD was recorded by Triax Smart Impact Monitor-G (SIM-G). *Results:* Each participant had an average of six headers (± 2.9 SD) with acceleration (minimum to maximum 27.5 ± 3.4 g to 57.4 ± 9.9 g) recorded by Triax SIM-G. K-D score time (42.9 ± 6.8 se conds compared to 41.6 ± 4.9 seconds, p = 0.37) and CTSIB-M sway index (0.79 ± 0.13 compared to 0.83 ± 0.13 cm, p = 0.17) pre- and post-test scores lacked statistical significance. *Conclusion:* It failed to show a correlation with head acceleration data (e.g., linear and rotational accelerations). A single soccer heading drill may not affect performance on the K-D and CTSIB-M. Regularly monitoring different metrics (e.g., K-D or CTSIB-M) for teams who practice more aggressive heading drills may inform training such skills while identifying potentially detrimental effects from repetitive soccer heading impacts during a competitive season.

Keywords: head injury; adolescent sports; postural control; saccades; repetitive head impacts

Introduction

Sport-related concussions (SRCs) are of increasing concern within the medical field (Malcolm, 2018), with 1.6 to 3.8 million cases in the United States annually (Langlois et al., 2006; Nathanson et al., 2016). Concussion rates in collegiate and high school soccer athletes are similar or greater to those in other contact sports (Levy et al., 2012; O'Connor, Baker, et al., 2017) with a higher prevalence among female soccer players, especially those in high school (O'Connor, Baker, et al., 2017), possibly due to differences in cervical musculature strength and head mass compared to males (O'Connor, Baker, et al., 2017; Tierney et al., 2008). No previous research has conclusively determined whether or not there are any deleterious effects on female soccer players after real-time repetitive head impacts (RHI) from heading a soccer ball both in the short and long-term.

One of the major causative factors of SRCs may be identified by and involve linear and rotational head acceleration forces (Duma & Rowson, 2011; Meaney & Smith, 2011; Post & Blaine Hoshizaki, 2015; Rowson & Duma, 2013). Acceleration combined with rapid deceleration of the head produces external force on the skull, resulting in brain tissue deformation and alterations in cranial pressure as the brain strikes the skull, potentially leading to a concussion (Meaney & Smith, 2011; Post & Blaine Hoshizaki, 2015). Head acceleration increases during soccer heading in both laboratory research and game play because of the cranial impact (Hanlon & Bir, 2012; Naunheim et al., 2003; Shewchenko et al., 2005). Most soccer concussions are due to player-to-player contact and not due to impacts from heading the soccer ball (Comstock et al., 2015). However, research is inconclusive regarding the role of soccer ball heading drill impacts on the influence of RHI on postural control. Lingering sub-clinical multi-system effects on postural stability performance (De Beaumont et al., 2011; Schmidt et al., 2018), or postural sway, and vestibular-ocular function (Kolev & Sergeeva, 2016; Rizzo et al., 2016) have been identified up to years after an initial concussive event; since these individuals are not complaining of overt symptoms of concussion, potential deficits may not be recognized. Schneider and coworkers (Schneider et al., 2013) identified subjective complaints of neck pain, headaches, or dizziness as potential pre-season risk factors for suffering a concussion during the season. It is not known how the impacts from heading a soccer ball may affect individual performance on standard concussion screening metrics with

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pre-season subjective risk factors or for those with a history of concussion compared to those without a history of concussion.

Several studies replicated soccer heading drills to determine their effects on postural and neurocognitive concussion screening metrics (Elbin et al., 2015; Gutierrez et al., 2014; Schmitt et al., 2004). Using a controlled laboratory environment, one study had subjects perform a heading drill by hand-tossing the ball to participants (Gutierrez et al., 2014). Other studies have used an automated-ball launcher to maintain constant velocity and height (Elbin et al., 2015; Schmitt et al., 2004). Head acceleration values (e.g., linear and rotational accelerations) in these controlled laboratory environments were found to be lower (20.3g and 1460 rad/s2) than that seen in real game environments (62.9 g and 8870 rad/s2) (Hanlon & Bir, 2012). Most studies found no significant differences in pre- and post-heading concussive screening metrics (Elbin et al., 2015; Gutierrez et al., 2014; Schmitt et al., 2004). Therefore, it is important and relevant to assess linear and rotational accelerations from RHI during an on-field soccer heading drill.

A study in 2004 by Mangus and coworkers failed to find an association with balance deficits after an acute bout of heading 20 soccer balls (Mangus et al., 2004). A 2016 meta-analysis by Kontos et al. indicated there were no overall effects of heading a soccer ball on various outcomes, including self-reported symptoms and postural control (Kontos et al., 2017). A 2021 study by Ashton et al. identified immediate negative effects on eye scanning (e.g., increased time during the King-Devick test) and working cognitive memory after an acute bout of 20 headers performed from a manually delivered ball (e.g., researcher delivered the ball using an underhand toss method) (Ashton et al., 2021). Aside from clear inconsistencies regarding the effects of heading drills in soccer, previous research failed to accurately simulate game-play, did not allow the athlete to run prior to heading the ball, and were absent of physical contact with other soccer players (Ashton et al., 2021; Elbin et al., 2015; Gutierrez et al., 2014; Hanlon & Bir, 2012; Kaminski et al., 2020; Kontos et al., 2017; Kontos et al., 2011; Schmitt et al., 2004). This study used a drill consisting of corner kicks and fighting another player to the ball (i.e., dueling to be the first to head the ball) to account for unpredictable conditions reflective of what happens in a game environment when heading a soccer ball.

After reviewing the above literature, it is evident that research on repetitive heading is limited to more controlled scenarios. This is concurrent with methods designed to gain specific end-point data without confounding variables. Game scenarios usually involve 6-12 high-velocity headers per game (Spiotta et al., 2012) in conjunction with inconstant ball direction, velocity, individual differences, and environments with multiple players competing for the ball, resulting in differences in acceleration variables. During a competitive season, the incidence of concussion from heading a soccer ball among female youth soccer players ranges from 25.3% to 30.5% (Comstock et al., 2015; O'Kane et al., 2014). Adolescent female soccer players with a history of concussion or pre-season complaints of headache, neck pain, or dizziness might be at higher risk of RHI during heading drills. Cumulative effects of RHI may be detectable by concussion metrics prior to obvious subjective symptoms. Therefore, research examining the effects of heading the ball in game-like environments using standard concussion metrics (e.g., eye scanning and postural control) is necessary to enhance the understanding the effects of heading the ball in a game-like environment. The purpose of this study was to evaluate any immediate RHI effects on two common concussion screening metrics after an acute bout of a soccer heading drill performed during a typical practice session. We hypothesized there would be no difference between assessment metrics after an acute bout of on-field soccer heading drill.

Materials and Methods

Participants

Subjects included 11 members of a public high school women's varsity soccer team, with participant characteristics as reported in Table 1. Each varsity athlete had three to six years of a higher level of competitive soccer experience, including club soccer participation and their high school team.

Table 1. Demographics of participants.

	Team Statistics
Age (yr)	16 (± 1.44)
Height (cm)	163.95 (± 5.64)
Body Mass (kg)	61.28 (± 6.57)
BMI	22.82 (± 2.38)

Data presented as mean (± standard deviation)
Abbreviations: yr = year; cm = centimeters; kg = kilograms.

Prior to participation, parents or guardians and participants reviewed the consent form and were given a copy of the approved Internal Review Board (IRB) study protocol and HIPAA authorization form. All subjects over 18 years old signed written informed consent prior to participation, and those under 18 years old signed written informed consent with their parent or guardian. Participants were excluded from the study if they answered "yes" to any of the seven questions on the *Physical Activity Readiness Questionnaire (PAR-Q) and You* form. In addition, participants over 18 years and parents of participants under 18 years completed an intake form providing data on demographic information, surgical history within the last three months, prior injury history, prior concussion history, and complaints of headache, neck pain, or dizziness at the time of testing.

Procedure

Baseline Clinical Test of Sensory Interaction on Balance (CTSIB-M) using Biodex Biosway® and King-Devick (K-D) scores were measured prior to the competitive soccer season in a high school gymnasium. The heading drill occurred after player acclimatization to the field and before any games or scrimmages and was the first heading drill performed that season. Subjects used a Triax Smart Impact Monitor-G (SIM-G) headband to measure head acceleration data and the number of headers performed. The team conducted a general warm-up session before the drill and had the CTSIB-M and K-D scores collected within five to 20 minutes following the drill (Figure 1).

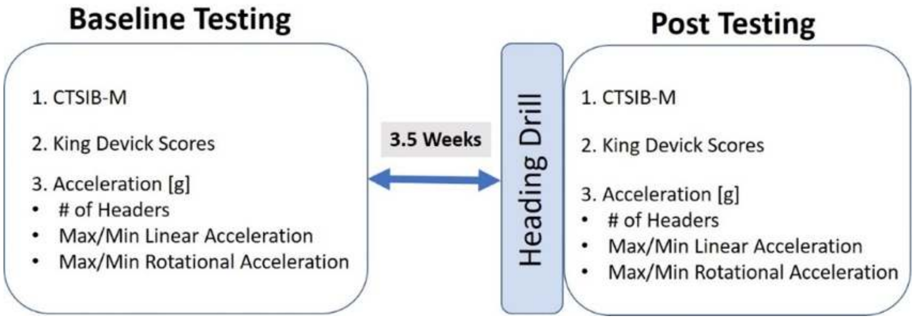

Fig 1. Observational Pre-test-Posttest Cohort Design.

Data Collection

King-Devick: K-D test is a screening tool used to assess cognitive visual impairments through saccadic eye movements following a suspected concussion (Oberlander et al., 2017). The test shows good reliability (ICC=0.81; 95% confidence interval= 0.73, 0.87) and validity (sensitivity= 0.98, specificity= 0.96, +LR= 11.6, PPV= 89%) (Hecimovich et al., 2018; Oberlander et al., 2017). Breedlove et al. (2019) also demonstrated K-D reliability between trials (ICC=0.89, $p < .001$) and between two consecutive years (ICC=0.83, $p < .001$)(Breedlove et al., 2019). The K-D test consists of three test cards containing varying lines of numbers (Figure 2). The participants were instructed to read the lines of numbers left to right, and top to bottom as quickly as possible with no errors. Time in seconds, without error, was the scoring metric for baseline data collection. Errors were monitored with the answer key and tests were restarted if errors occurred. Errors were permitted and noted without retesting during post-test data collection.

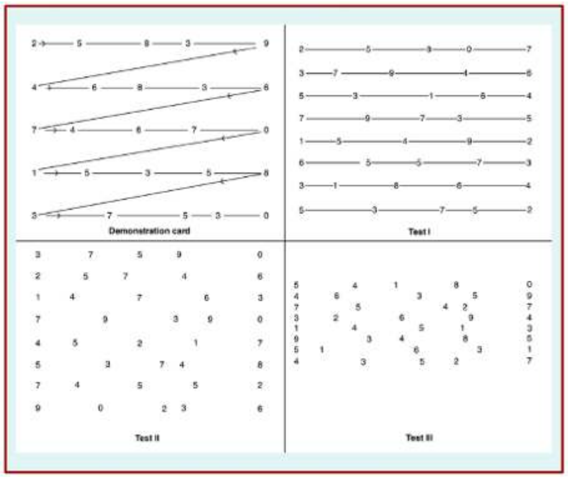

Fig 2. King-Devick. Each card is separately read and timed in seconds.
Photo credit: https://www.researchgait.net

CTSIB-M: The modified CTSIB (CTSIB-M) is one of the most common balance assessments referenced in concussion literature (Cripps et al., 2018; Guskiewicz, 2011; Riemann & Guskiewicz, 2000). In this study, CTSIB-M was performed on the Biosway force plate (Figure 3), which has shown good reliability (ICC =.895; 95% CI =.809-.946, p<.001) (Seymour et al., 2015), to measure outcome variables of postural sway and balance impairment (Caroline J Ketcham, 2015; Dewan et al., 2019; Miner et al., 2022; Miner et al., 2020). Prior to CTSIB-M testing, height and age were inputted into the Biosway and participants were instructed to remove shoes and socks. Participants feet and body were positioned on the force plate so that a green circle on the machine's screen was aligned directly in the center and documented for post-test placement, representing appropriate calibration of each individual's center of gravity. Participants were informed that they would remain in this position throughout testing and were told to ensure their body positioning was comfortable. Foot placement was then measured to ensure consistent foot placement throughout testing once foam mats were added to the force plate. Participants were informed to stand as steady as possible throughout testing. CTSIB-M consists of four testing conditions, each lasting 30 seconds: standing on force plate eyes open, standing on force plate eyes closed, standing on foam placed on force plate with eyes open, and standing on foam placed on force plate with eyes closed.

Fig 3. Biodex BioSway. The four conditions of the CTSIB-M (eyes open/closed on stable/foam surfaces) were performed on a force plate.

Triax: Nonhelmeted head impact sensors, like the Triax, collect real-time data regarding exposure to such forces (O'Connor, Rowson, et al., 2017). The Triax Smart Impact Monitor-G (SIM-G) uses the SKYi system (Figure 4) to record and display for identification the number of headers performed during the heading drill and the amount of head acceleration (e.g., linear and rotational accelerations) per single heading episode. Prior to the heading drill, participants were fitted for a headband that contained the SIM device. The SIM-Gs were turned on and linked to the Triax SKYi data recording device. The headband was placed around the player's head so that the SIM rested on the posterior skull at the level of the external occipital protuberance, and the front of the headband was above the player's eyebrows. Once participants completed the 15-minute heading drill, the SIMs were simultaneously turned off utilizing the SKYi device. Data was extracted from the SKYi device utilizing the Triax Cloud Dashboard.

Fig 4. Triax ™ Smart Impact Monitor (SIM-G) & SKYi Box.

Heading Drill: Subjects were positioned in two lines 18 yards (16.5 meters) away from the goal on a grass field. Two team members were positioned at both corner flags adjacent to the goal (15-20 yards [13.7-18.3 meters] from the goal). The first subject in each line ran forward toward the goal as one ball was kicked in front of the goal from the corner of the field, known as crossing after a corner kick. Subjects attempted to score a goal using their head during the heading duel drill. The subject ran to the back of the line while the next subject ran forward and attempted to head the cross kicked ball into the goal (Figure 5 and 6). This was repeated for a total of 15 minutes. Soccer balls were crossed from both corners of the field at various heights and speeds, forcing players to make positional adjustments to properly head the ball. Researchers did not evaluate or confirm the quality of the header, but ensured the devices were recording when the header occurred.

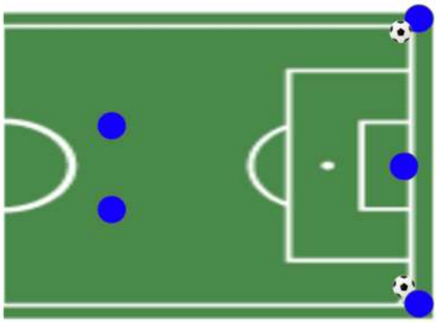

Fig 5. Heading Drill. Players formed 2 lines 18 yards (16.5 meters) away from the goal on a grass soccer field with 2 players were positioned at each corner flag, 15-20 yards (13.7-18.3 meters) from goal. One ball was served from one of the two corner flags as 2 players ran towards the goal, player who got to the ball first headed the ball towards the goal attempting to score.

Fig 6. SIM-G Impact Sensor. Ecologically valid on-field environment.

Statistical Analysis

Each player headed the ball an average of six times (± 2.9 SD). Participates were reassessed using the CTSIB-M and K-D within five to 20 minutes of completing the drill. The Shapiro-Wilk test identified normality as violated. Mean baseline test scores of King-Devick and CTSIB-M were compared to mean post-test scores following the header drill utilizing the Wilcoxon signed-ranks test. Spearman correlation was conducted to determine if there was an association between the number of prior concussions to baseline and post-heading drill scores.

Spearman correlation was also utilized to analyze the association between K-D and CTSIB-M scores with linear and rotational accelerations. According to previous history of neck pain, headache, and concussions, groups were analyzed for differences in baseline and post-heading drill K-D and CTSIB-M scores using analysis of covariance with baseline scores as a covariate. All statistical procedures were performed using SPSS Statistics (Version 24.0, IBM, Armonk, New York), with significance determined at a p-level of < 0.05.

Results

Eleven players, 16 (±1.44) years old with a BMI of 22.82 (±2.38) (Table 1), performed the heading drill, each averaging 6.08 headers and ranging from 3.21 to 8.95 headers total. These head impacts created linear acceleration forces between 27.54 (±3.35) and 57.38 (±9.95) g and rotational head acceleration forces between 2720 (±750) and 6100 (±2360) rad/s^2 (Table 2). No significant differences were observed between baseline and post-heading drill scores on K-D and CTSIB-M.

Although not statistically significant, K-D scores improved slightly from 42.88 (±6.78) to 41.64 (±4.90) seconds while CTSIB-M sway index worsened slightly from 0.79 (±0.13) to 0.83 (±0.13) centimeters (Table 2). In addition, subjects with previous concussions or with pre-season complaints of headaches or neck pain (Table 3, 4, and 5) had no statistical differences in pre- and post- K-D and CTSIB-M scores.

Post heading raw data for K-D and CTSIB-M trended towards worse in subjects with a concussion history (Table 3). Spearman correlation revealed no significant association between the number of previous concussions and baseline and post-heading drill scores. There were no significant correlations between K-D and CTSIB-M scores and head acceleration (e.g., linear and rotational) data.

Table 2. Cumulative metric scores.

	N = 11
Number of headers	6.08 (± 2.87)
Minimum Linear Head Acceleration (g)	27.54 (± 3.35)
Maximum Linear Head Acceleration (g)	57.38 (± 9.95)
Minimum Rotational Head Acceleration (rad/s2)	27200 (± 750)
Maximum Rotational Head Acceleration (rad/s2)	6100 (± 2360)
Baseline K-D (sec)	42.88 (± 6.78)
Post HD K-D (sec)	41.64 (± 4.90)
Baseline CTSIB-M Composite Sway Index (cm)	0.79 (± 0.13)
Post-HD CTSIB-M Composite Sway Index (cm)	0.83(± 0.13)

Data presented as mean (± standard deviation).
Head acceleration data is based on mean acceleration of all headers performed during the heading drill.
Abbreviations: g = g-unit, where 1-g or 9.81N is the force experienced by unit mass due to gravitational acceleration where 1-g or 9.81N is the force experienced by 1kg mass for acceleration due to earth's gravity; % = percentage; rad/s2 = radian per seconds squared; K-D = King-Devick test; HD = heading drill; sec = seconds; CTSIB-M = modified clinical test of sensory interaction on balance; cm = centimeters.

Table 3. Mean K-D and CTSIB-M scores for subjects with a history of concussion versus those with no history of concussion.

	Concussion (N = 4)	No Concussion (N = 7)
Baseline K-D (sec)	41.30 (± 6.59)	43.79 (± 7.24)
Post-HD K-D (sec)	44.50 (± 5.39)	40.01 (± 4.12)
Baseline CTSIB-M Composite Sway Index (cm)	0.80 (± 0.20)	0.78 (± 0.08)
Post-HD CTSIB-M Composite Sway Index (cm)	0.92 (± 0.17)	0.78 (± 0.07)

Data presented as mean (± standard deviation).
Abbreviations: K-D = King-Devick test; HD = heading drill; sec = seconds; CTSIB-M = modified clinical test of sensory interaction on balance; cm = centimeters.

Table 4. Mean K-D and CTSIB-M scores for subjects with a history of headaches versus those with no history of headaches.

	Headache (N = 5)	No Headache (N = 6)
Baseline K-D (sec)	39.65 (± 2.41)	45.57 (± 8.27)
Post-HD K-D (sec)	38.68 (± 4.11)	44.11 (± 4.29)
Baseline CTSIB-M Composite Sway Index (cm)	0.81 (± 0.16)	0.78 (± 0.11)
Post-HD CTSIB-M Composite Sway Index (cm)	0.83 (± 0.20)	0.83 (± 0.05)

Data presented as mean (± standard deviation).
Abbreviations: K-D = King-Devick test; HD = heading drill; sec = seconds; CTSIB-M = modified clinical test of sensory interaction on balance; cm = centimeters.

Table 5. Mean K-D and CTSIB-M scores for subjects with a history of neck pain versus those with no history of neck pain.

	Neck Pain (N = 4)	No Neck Pain (N = 7)
Baseline K-D (sec)	40.70 (± 1.20)	43.70 (± 7.91)
Post-HD K-D (sec)	37.80 (± 4.67)	43.08 (± 4.40)
Baseline CTSIB-M Composite Sway Index (cm)	0.68 (± 0.09)	0.83 (± 0.12)
Post-HD CTSIB-M Composite Sway Index (cm)	0.75 (± 0.07)	0.86 (± 0.12)

Data presented as mean (± standard deviation).
Abbreviations: K-D = King-Devick test; HD = heading drill; sec = seconds; CTSIB-M = modified clinical test of sensory interaction on balance; cm = centimeters.

Discussion

The aim of this study was to investigate the effect of a single soccer heading drill in an on-field real-life ecological environment in which RHI occurred and found no significant immediate changes on the concussion screening metrics (e.g., K-D and CTSIB-M sway index).

Recently, one study reported an increase in self-reported concussion symptoms within 24 hours of the automated-ball launcher heading drill (Schmitt et al., 2004). Another study found verbal memory deficits, indicative of concussive symptoms, after heading drills, even with protective headbands (Elbin et al., 2015). A study by Kaminski et al. (2020) studied the effect of an acute heading drill on collegiate female soccer players to compare those with and without a history of concussion(Kaminski et al., 2020). A heading drill was performed on-field with the ball trajectory from two different directions to simulate linear and rotational heading forces with 15 headers from each direction. An automated-ball launcher was used to achieve a constant ball speed (11.2 m/s or 25 mph) for both flight paths toward participants at a set distance, between 9.1 to 13.7 meters. Kaminski et al. (2020) found negligible differences in postural control (e.g., BESS) and neurocognitive performance (e.g., ImPACT) between those with and without a history of concussion but did identify a difference in self-reported concussion-related symptoms with primary reports being headache, fatigue, and drowsy/sleepy. Although the Kaminski study appears to be the first study to be perform purposefully in the same ecological environment where athletes play soccer, the rate at which the ball was delivered to the participant was constant and not a direct simulation of a standard practice or game environment. The present study is the first study the authors are aware of that is an ecological representation of heading impacts within realistic environments in which such activities occur.

A previous study utilized questionnaire data on self-reported heading history and performance, MRI imaging, and cognitive functioning tests to determine if heading caused subclinical evidence of traumatic brain injury (TBI) (Lipton et al., 2013). They found that, despite a large quantity of reported headers (ranging from 32-4,500 total headers), psychomotor speed, attention, and executive function were not affected by the heading drill. Our results are consistent with similar studies that have assessed acute bouts of soccer heading on neurocognition and control tests in athletes (Elbin et al., 2015; Gutierrez et al., 2014; Schmitt et al., 2004). Previous studies have found that an acute bout of heading did not affect high school female scores on the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT), a measure of cognition (Elbin et al., 2015; Gutierrez et al., 2014; Schmitt et al., 2004), or on postural control (Schmitt et al., 2004). These three study designs (Elbin et al., 2015; Gutierrez et al., 2014; Schmitt et al., 2004) were similar to our study in that each had limited subjects ranging from 17 to 31 with exposure to 15-18 total headers. In contrast, our study had 11 subjects who experienced 6.08 (±2.87) headers. During game situations, the average number of headers a player may be exposed, where the ball has the similar velocity as our heading drill, is between 6-12 exposures (Spiotta et al., 2012). However, the actual frequency of heading events during play is not definitive (Chrisman et al., 2019; Dave et al., 2022). These study designs differed from our own as their participants stayed in a stationary position or approached the ball in a predetermined manner, and were instructed to head the ball in a specific direction as the ball was either hand-toss or delivered by a ball launcher (Elbin et al., 2015; Gutierrez et al., 2014; Schmitt et al., 2004). Furthermore, head acceleration an important parameter for evaluating heading forces was not always assessed (Elbin et al., 2015; Schmitt et al., 2004).

All inertial measurement unit systems have been reported to have error rates. We have utilized Triax (nonhelmeted impact sensors) in this study. A similar system, the X-Patch using similar accelerometer and gyroscope technology, has an error rate up to 50% with a positive prediction value of 16.3%, and, as such, this should always be considered during interpretation (McCuen et al., 2015; Press & Rowson, 2017). Clinical applicability is limited due to error rates for these head impact monitoring systems (O'Connor, Rowson, et al., 2017); however, these systems do serve as a potential indicator that an individual may have sustained a head impact that may require further assessment (O'Connor, Rowson, et al., 2017). The SIM-G provided reliable linear and rotational acceleration data at lower levels of impact (e.g., 30 g or 50 g) when compared to Hodgson-WSU headform reference sensors (Karton et al., 2016), with potential mean absolute value of error rates between 10-20% (Cummiskey et al., 2016). Within a controlled lab environment, the SIM-G sensor reliably measured impacts of short duration (7 ms), simulating a head striking the ground, and long duration (40 ms), simulating a ball striking the head such as occurs with heading a soccer ball, suggesting the SIM-G may reliably collect linear and rotational acceleration data during head motions (Allenstein, 2017; Kanton et al., 2018; Oeur et al., 2016). The SIM-G's tendency to measure more accurately lower force impacts versus higher impacts (which it overestimates) provides a conservative identification of high-risk head impacts (Allenstein, 2017; Kanton et al., 2018). Multiple studies have successfully used the SIM-G to monitor head impacts within laboratory study designs(Huber et al., 2021) and for studies designed where the SIM-G collected in-field data, including youth football(Le et al., 2021), collegiate club water polo (Cecchi et al., 2020), collegiate soccer for both sexes (Caccese et al., 2018), and adolescent high school soccer for both sexes (Patton, Huber, McDonald, et al., 2020). Despite sensor preference within research, for example the skin mounted sensors (e.g., X-Patch) (Rowson & Duma, 2020; Schussler et al., 2017) or mouthguard sensors (King et al., 2015; Rowson & Duma, 2020), there have been multiple recent systematic reviews (Le Flao et al., 2022; O'Connor, Rowson, et al., 2017; Patton, Huber, Jain, et al., 2020) which have identified the use of the SIM-G as an *in vivo* sensor to record RHI. The SIM-G was selected for this study based on its mid-range price point (approximately $150 per device), making it accessible and relatively easy to operate and manage.

More predictable data is attainable using an automated-ball launcher to achieve a consistent speed and ball direction prior to heading impacts. One study used this method to compare those with and without a history of concussion during an on-field heading drill and found significant increases in self-reported concussion-related symptoms, such as primary reports of headache, fatigue, and drowsiness or sleepiness, in those with prior concussion histories (Kaminski et al., 2020). Our study differed since the speed and trajectory of the ball was uncontrolled and unpredictable, similar to the inconsistent ball trajectory of on-field game situations and complicated by the inability to anticipate ball position prior to impact. Despite the non-significance of our findings, those with a history of concussion had poorer raw K-D and CTSIB-M scores. Perhaps more head impacts during data collection would have influenced this finding as the participants incurred an average of six head impacts (±2.9), in contrast with 12 to 20 heading drill impacts typical of other research evaluating RHI (Ashton et al., 2021; Caccese et al., 2018; Gutierrez et al., 2014; Kontos et al., 2011; Mangus et al., 2004).

Prior research has established baseline card King-Devick (K-D) times to be 39.3±5.6 (Aron et al., 2022), 40±6.3 (Harper et al., 2022), and 40.0 (Clugston et al., 2020) seconds. Higher baseline K-D scores have been recorded in younger athletes of 12-14 years of age (Harper et al., 2018). The King-Devick (K-D) test may be sensitive enough to identify changes directly after ball heading drills. Immediate adverse effects were detectible on healthy controls by the K-D test after an acute bout of heading 20 consecutive soccer balls with standard inflation. Post-heading test results included longer times (mean 4.4 seconds) and increased errors (mean 1.45), changing from baselines averaging 40 seconds to post-heading K-D scores ranging from 42 to 48 seconds (Ashton et al., 2021). Unlike the significant differences in K-D post heading scores found by Ashton et al. (2021), our study did not identify a significant difference in K-D scores (Ashton et al., 2021). However, it did identify increased K-D times post heading drill (44.5±5.4) in those with a history of concussion compared to those with no history of concussion (40.0±4.1). It is possible the differences in K-D scores might be related to the limited number of impacts, six compared to an average of 20 (Ashton et al., 2021), and the increased time between headers and post-testing in this study.

Multiple factors are involved in head impact severity and can be measured using the SIM-G. Using this technology, one study found head mass significantly predicted rotational acceleration, and sternocleidomastoid muscle strength significantly predicted peak linear and rotation acceleration (Caccese et al., 2018). Since strength is a modifiable factor, and head mass is not, Caccese et al. recommend females strengthen their neck muscles to more optimally attenuate forces during purposeful heading (Caccese et al., 2018). However, developing large, thick neck muscles is not a priority for young female adolescents. Fortunately, increased neck strength and girth following neck strengthening exercises in collegiate soccer players of both sexes has not been shown to increase the ability to mitigate forces from purposeful headings (Mansell et al., 2005). Neck muscle strength is not the sole determining factor for decreasing head impact forces during heading for either female or male athletes (Mansell et al., 2005). Instead, improving neuromuscular control and dynamic stabilization appears more optimal for those exposed to RHI (Mansell et al., 2005). Despite robust findings from prior research (Caccese et al., 2018; Dezman et al., 2013; Peek et al., 2020), improving neck strength alone may not be the only way to address this modifiable risk factor, especially for adolescent female soccer athletes who may not consider large, thick necks desirable. There may be other means by which to address this modifiable risk factor.

For example, if the participant knows the ball trajectory, header technique becomes less of a confounding variable to the forces generated since athletes with more experience tend to use specific heading strategies (Caccese et al., 2018). Head impact accelerations may be related to the anticipated ball position at impact; thus, if a player predicts the ball's position accurately, the header will be performed using a consistent movement pattern (Caccese et al., 2018). Because of this relationship between anticipatory positioning and a controlled delivery, it is possible that knowing the predetermined flight path of the ball in a controlled throw study environment might result in consistent heading movement patterns reflective of the consistent testing environment. Our study attempted to address this by obtaining data during a real-time heading drill with uncontrolled ball flight paths and velocities. The athlete had to adjust their movement in real-time while anticipating the ball position at time of head impact for each unique heading attempt. This concept is consistent with research speculating that head impact forces may be more dependent on movement direction (Bretzin et al., 2017; Eckersley et al., 2019), specifically, the athlete's position in relation to the ball, their movement toward the anticipated location of contact while a competing player is in the vicinity, the exact location of the ball when contacted with the head, and the speed of the ball. Therefore, although increased neck strength is one component of decreasing RHI in soccer, it is not the sole mitigating factor in limiting sports-related concussions (Bretzin et al., 2017; Eckersley et al., 2019; Mansell et al., 2005)

The present study evaluated head acceleration forces during a relatively intense heading drill in an ecologically valid on-field environment where the participant had to anticipate the ball's flight path while running to head the ball toward the goal. Our study found that the average number of headers or head impacts was 6.08 (±2.87), with linear acceleration between 27.54 (±3.35) and 57.38 (±9.95) g and rotational head acceleration forces between 2720 (±750) and 6100 (±2360) rad/s^2. These forces are consistent with other nonhelmeted head sensors (e.g., X-Patch) for female high school soccer players during play, with impacts of 37.56 g and rotational head acceleration forces of 7500 rad/s^2; however, the average number of head impacts was only 2.05 per session of play (McCuen et al., 2015), while in our study, it was about three times the number of impacts during a heading drill session.

A previous study found that most concussions in women's and men's collegiate soccer occur from unintentional head impacts, such as head-to-head contact between two players, rather than heading the ball (Comstock et al., 2015; Levy et al., 2012). No unintentional head impacts were present during our study because the subjects positioned themselves to receive and voluntarily head the ball during the drill. Player anticipation of impact may have limited the degree of head acceleration leading to no significant impairments on the screening metrics. This is supported by the finding that volitional cervical musculature contraction in anticipation of head impact reduces linear and angular head velocity when compared to impacts with no anticipatory muscle contraction (Eckner et al., 2014); thus, muscles may dampen the forces of heading impact in predictable environments, like heading a soccer ball, but are less likely to attenuate such forces from an unanticipated head-to-head impact. One study which evaluated neurocognitive function and balance on female soccer players following a full season of purposeful heading found no significant changes in either neurocognitive function or balance tests (Kaminski et al., 2007). In contrast, a recent study found self-reported intentional heading performed within two weeks of testing to be significantly correlated with an inverse relationship with performance on psychomotor speed, attention, and working memory compared to unintentional head impacts (Stewart et al., 2018). These differences in intentional versus unintentional head impacts may be explained by the variations in time lapsed from heading drill to post testing. Our study performed post testing within 20 minutes after heading, which is sooner compared to two weeks following heading (Stewart et al., 2018), or at the end of the season (Kaminski et al., 2007). Previous findings suggested that deficits in the K-D may not be present immediately following a probable concussive event due to the prolonged duration of the neural cascade event, and recommended waiting a minimum of 15 minutes before performing the K-D assessment (King et al., 2012). However, in this study we tested K-D within five to 20 minutes of the heading drill since the intent was to determine the immediate effects and influence of heading impacts to saccadic eye movement and postural sway since these athletes continue to play and may be subject to repeated sub-threshold impacts during continued participation.

Although heading did not have a negative impact on balance and K-D, it may be that an athlete with a previous concussion might be more susceptible to experiencing subtle changes in balance or other concussion metrics. To assess this assertion, a further analysis of our data included a subset of subjects with a history of concussion. Unfortunately, due to the small number of subjects in this study, no statistical differences were identified between those with and without a history of concussion. Despite this limitation, raw data trended toward a correlation between heading impacts and subject's performance on the two metrics, K-D and CTSIB-M (Table 3). Therefore, more subjects are needed to elucidate this trend. Data trends like this may initiate discussions regarding the use of screening metrics to identify lingering subclinical effects of concussions, especially with pre-season risk factors of neck pain and headache, and the necessity of periodic in-season monitoring for the influences of RHI on these metrics (e.g., K-D and CTSIB-M postural sway) when soccer heading drills are consistently utilized.

There are several potential limitations of this study. The baseline collection of the K-D and CTSIB-M was collected indoors and post-heading drill assessments were done in an open environment where possible ecological distractions may have occurred. However, this open style of testing environment may reflect the sideline concussion screening environment during a game. Sample size was also a limitation of this study. A small sample size was chosen due to limited access to head sensor equipment and was focused at exploring unique patterns when athletes duel to head a soccer ball as show by a single cohort after a bout of acute headings. The heading drill was set up to be more ecologically valid as it occurred in a realistic practice environment as two athletes dueled to head the ball, however, it also resulted in a different number of headers for each participant, which may have skewed results. Post-testing occurred between five and 20 minutes after the heading drill depending on when each individual athlete was tested, which may have influenced the findings. The K-D has known learning effects in individuals without concussion (Leong et al., 2015), which may be a potential limitation when accounting for baseline and post-heading drill K-D scores. The SIM-G sensor technology may be considered a limitation; however, this same device has been utilized as device to collect accelerations for head impact data in multiple research studies (Caccese et al., 2018; Cecchi et al., 2020; Huber et al., 2021; Le Flao et al., 2022; Le et al., 2021; O'Connor, Rowson, et al., 2017; Patton, Huber, Jain, et al., 2020; Wahlquist & Kaminski, 2021).

The results of our study might be helpful for training professionals towards preventing concussive events, as the act of heading a soccer ball results in more incidences of concussion than during other aspects of the game (O'Kane, 2016). A systematic review identified that female soccer players have a higher incidence of concussion from the act of heading, primarily attributed when contesting a ball (i.e., heading duel) than their male counterparts (Dave et al., 2022). The number of headers increases with older players when attacking contested balls (i.e., dueling) in the same field area where this heading drill occurred, specifically from long-range corner kick delivery (Peek et al., 2021). Heading guidelines in youth soccer have been developed to limit heading exposure from teaching heading in controlled environments, using small or softer balls during training, not allowing heading below 10 years of age, to limiting heading to training only between 11-13 years but not allowed during game conditions, and some not allowing heading until the athlete is 18 years of age, to name a few (O'Kane, 2016; Peek et al., 2021). However, reducing heading exposure may reduce the number of heading accumulation of forces but may result in the lost opportunity of coaches to provide instruction on proper form, especially when dueling for contested soccer balls during heading (Peek et al., 2021). Our results inform coaches regarding the potential use of similar heading drills in female adolescent athletes. Limiting similar heading drills allows athletes to learn how to manage during such natural conditions without overly exposing athletes to potentially more significant forces from RHI. Despite non-significance, the data was trending toward significance, indicating that deficits might be identified if this drill was repeated several times during a competitive season. Using non-helmeted sensors can help monitor the number and forces of impacts from heading the ball to prevent the cumulative effects of repeated non-concussive hits. Furthermore, consistent monitoring of athletes during the season using different metrics (e.g., K-D or CTSIB-M) to identify deficiency or trending toward poorer performance on these metrics might be helpful to identify potential detrimental effects from RHI during a competitive season.

Conclusions

Overall, our study suggests that field of play soccer heading drills with less than 10 head impacts, may not be associated with immediate deficits on concussion screening metrics in adolescent female high school athletes. In an attempt to improve the safety of female soccer participation, especially within competitive teams which play at a higher level of aggressive play, it may be useful to monitor the number of impacts from heading drills and the magnitude of heading impacts. It is possible that an increased amount of head impacts through multiple heading drills during the course of the season might result in statistically relevant deficits, which may manifest without immediate overt signs in postural stability or oculomotor function.

It may be speculative that intentional head impact may create a protective movement pattern that is not disrupted by a few RHI. In an attempt to improve the safety of adolescent female soccer players, it may be useful to monitor the impacts of heading a ball, especially in those reporting a concussion history. In order to fully evaluate the utility of this type of heading impact monitoring, future research could involve a longitudinal study design of multiple head impacts conducted over a longer period of time with monitoring self-reported concussion-related symptoms, K-D test, and postural sway (e.g., CTSIB-M).

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