The Relationship Between Impact Force, Neck Strength, and Neurocognitive Performance in Soccer Heading in Adolescent Females

Gregory M. Gutierrez
New York University

Catherine Conte
Ossining High School

Kristian Lightbourne
Polytechnic Institute of New York University

Head impacts are common in contact sports, but only recently has there been a rising awareness of the effects of subconcussive impacts in adolescent athletes. A better understanding of how to attenuate head impacts is needed and therefore, this study investigated the relationship between neck strength, impact, and neurocognitive function in an acute bout of soccer heading in a sample of female high school varsity soccer players. Seventeen participants completed the ImPACT neurocognitive test and had their isometric neck strength tested (flexion, extension, and bilateral flexion) before heading drills. Each participant was outfitted with custom headgear with timing switches and a three-dimensional accelerometer affixed to the back of the head, which allowed for measurement of impact during heading. Participants performed a series of 15 directional headers, including 5 forward, 5 left and 5 right headers in a random order, then completed the ImPACT test again. Neurocognitive tests revealed no significant changes following heading. However, there were statistically significant, moderate, negative correlations ($r = -0.500$–$-0.757$, $p < .05$) between neck strength and resultant header acceleration, indicating that those with weaker necks sustained greater impacts. This suggests neck strengthening may be an important component of any head injury prevention/reduction program.

**Keywords:** adolescent, strength, exercise training, gender, sport medicine, biomechanics

Sport-related head injuries are common among adolescent athletes, specifically in contact sports such as football, ice hockey, and soccer (26). Considering that tens of millions of adolescents participate in organized sports, even small percentages of injuries can result in millions of affected individuals. In fact, it has been estimated that as many as 3.8 million mild traumatic brain injuries occur annually in the United States (16). However, a true estimate is difficult to attain, due to underreporting and underdiagnoses (21). More problematically, subconcussive impacts to the head (i.e., impacts not resulting in a clinically identifiable concussion) may be linked to long-term degeneration of cerebral tissue (7). These subconcussive impacts can happen dozens of times during the course of a contact-sporting event with no form of medical diagnosis or intervention, especially in sports like football and soccer.

Most concussive injuries that occur in soccer are caused by direct contact (i.e., head vs. head, head vs. knee, head vs. the ground), or a whiplash-type motion in which the brain is stunned through the accelerated motion of the head snapping forward and/or backward. However, what makes soccer unique is that the players purposefully use their unprotected heads to pass, shoot, redirect, and stop the ball offensively and defensively. In fact, heading is such an integral part of game play that a soccer player can be subjected to an average of 6–7 headers (subconcussive impacts) per game at the professional level (27). Kaminski et al. (14) found that female high school soccer players averaged just less than one header per game, while female collegiate players averaged almost three headers per game, over the course of a season. It should be noted that these totals do not
include headers during practices, which could add a substantial number of head impacts to the yearly total. Taken together, this suggests that the longer an athlete plays soccer (which is often dictated by the quality of their play), the more likely they will suffer from a higher number of subconcussive impacts during their career. Headed balls travel at high velocities pre- and post-impact, implying a range of potential cerebral damage (28). There is a deficit in literature regarding the exact biomechanics and complications (both immediate and long term) of cerebral damage resulting from purposeful heading (23). While it has been established that even over the course of a season, purposeful heading may not result in neurocognitive deficits (14), the evidence is mixed on the relationship between heading and cognitive function over the course of an entire career (15,19,20,29).

In rankings of the most concussion prone sports for adolescent athletes, women’s soccer is consistently in the top 3, following only football and wrestling (8,26). Research also suggests that females may suffer significantly worse deficits following a concussion (5). There exists a gender disparity in subconcussive impacts in soccer, which may be due to anatomical and biomechanical differences. Specifically, females may be at higher risk due to differences in body composition and neck strength, suggesting that females may be a more susceptible group warranting further research. This is especially true in the adolescent population where overall strength has yet to develop and recovery from head injuries may be delayed relative to adults (6).

Studies have been performed involving in-helmet accelerometers in football players, but data from athletes such as soccer players, who do not wear helmets, is limited due to the lack of an acceptable method for affixing the accelerometer to the players’ heads (11). Although they did not evaluate heading specifically, Mansell et al. (18) evaluated the effect of an 8-week neck-strengthening program on the head-neck dynamic restraint system in collegiate soccer players and found that even though neck strength improved, the dynamic restraint mechanism was not enhanced. Tierney et al. (31) monitored acceleration of the skull during heading in males and females using a mouthpiece equipped with an accelerometer. They reported that females have greater head-neck segment acceleration than males when their heads are subjected to the same load in a heading task. These differences are attributed to females’ having less head mass and neck girth, leading to less head-neck segment stiffness and strength than males. More recently, Dezman et al. (4) found that symmetrical strength in the neck flexors and extensors was correlated with reduced head acceleration during low-intensity heading. Their findings suggest that the head-neck segment dynamic restraint system could provide protective properties similar to those demonstrated in the ankle, knee, and shoulder (18). This mechanism could potentially help athletes better prepare themselves to endure the impacts received from heading, however there is insufficient evidence in the literature to make definitive conclusions concerning the specific relationship between neck strength and head acceleration during soccer heading.

The purpose of this research was twofold. First, we aimed to determine if impacts from heading a soccer ball cause neurocognitive deficits in female high school varsity soccer players following an acute bout of heading. Secondarily, we aimed to evaluate the relationship between neck strength and head acceleration/impact in those individuals. It was hypothesized that typical forces experienced in a soccer heading drill will not cause neurocognitive function to decline, but neck strength will be correlated with head acceleration.

**Methods/Procedures**

**Research Design**

The study design was twofold to address each aim. First, to assess the effect of soccer heading on neurocognitive function, a pretest-posttest design was used to evaluate changes in ImPACT test scores following an acute bout of heading. To evaluate the relationship between neck strength and header impact, a cross-sectional approach was used in which neck strength and header impact were collected during the single test session.

**Participants**

Seventeen female varsity high school soccer players from the same school team volunteered to participate in the study (mean ± SD; age = 15.9 ± 0.9 years, height = 1.65 ± 0.06 m, mass = 59.0 ± 5.6 kg). Before testing, parental consent and participant assent was attained. On testing day, subjects reported to the local high school gym which allowed for some level of environmental control while providing adequate space for participants to freely move while performing the header drills. They first completed a custom questionnaire that collected basic demographic information, asked about their physical activity level, and monitored for inclusion/exclusion criteria. To participate, subjects met the following criteria: be between the ages of 14 and 18 years old; be a female high school varsity soccer player; have knowledge and experience on how to head a soccer ball; and have no conditions that may influence movement patterns or past history of muscle, heart or lung disease.

**Instrumentation**

The ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing; Impact Applications, Inc., Pittsburgh, PA) computerized test was used to measure neurocognitive function, including: working visual and verbal memory, processing time, attention span, sustained and selective attention time, response variability, nonverbal problem solving and reaction time. ImPACT is a 20-min test that has become a standard tool used in comprehensive clinical management of concussions for athletes aged 10 years through adulthood.
Participants’ neck strength was measured using a digital handheld dynamometer (MicroFET2, Hoggan Health Industries, Inc., Draper, UT) in four different directions (i.e., flexion, extension, left lateral flexion and right lateral flexion) by the primary investigator. Pilot testing before the investigation found the investigator was reliable using the dynamometer; ICC values ranged from 0.93–0.96, depending on neck strength direction.

To monitor header impact, subjects were equipped with a custom headband, which held a triaxial accelerometer (Type 8690C5, Kistler Instrument Corp., Amherst, NY) to the back of their head (opposite from where they will be heading the ball). The accelerometer measured impact in three planes—anterior/posterior, right/left, and superior/inferior. From this data, the resultant header acceleration could be calculated. Two electronic timing switches (Delsys Inc., Boston, MA) were also attached on the forehead above each eyebrow, which allowed for identification of ball contact with the head. The equipment set-up is depicted in Figure 1a. All analog data were collected synchronously using a laptop computer equipped with a 16-bit analog-to-digital converter (6036-E, National Instruments Corp., Austin, TX), at a sampling rate of 1000 Hz, with custom designed LabView software (version 8.6, National Instruments Corp., Austin, TX).

**Procedures**

After providing parental consent and subject assent, as well as completing the demographic/inclusion questionnaire, subjects began testing by completing the ImPACT neurocognitive test. Once the test was completed, subjects were seated for neck strength testing. The directional order was randomized between subjects and each direction was tested 3 times consecutively with 30 s rest breaks between trials. The average of the peak values from all 3 trials was used for analysis.

Once the strength testing was completed, subjects were equipped with the accelerometer and timing switches, affixed to the head using an elastic strap, and instructed on the testing procedures. The heading protocol was conducted to mimic the regular header drills they performed in practice. Specifically, a trained soccer player performed a standard throw-in from 30 feet away; the same individual performed the throw-ins for all subjects. Before each throw, subjects were instructed to direct the ball to the left, right, or straight back to the person throwing them the ball in a randomized order with approximately 30–60 s between headers. While this heading procedure was not as controlled as other studies evaluating headers (e.g., Tierney et al. [31] used a JUGS machine to project the balls), we chose to use this protocol because it more closely mimicked a real-life header drill these athletes performed during practice. Further, our protocol provided a wider range of impacts than a tightly controlled experimental set-up, which allowed us to make a more robust evaluation of the relationship between neck strength and header impact. Subjects were asked to stand on an ‘x’ marked by tape on the ground and they were not allowed to step off of it to complete a header. If they could not complete the header, the trial was discarded and the heading drill continued in a randomized fashion. The experimental set-up is depicted in Figure 1b. Fifteen acceptable headers were collected in total (5 in each direction). After the heading drill, the cap and sensors were removed and participants were asked to complete the ImPACT test again.

**Data Analysis**

The composite scores were extracted from the ImPACT software and used for analysis. Paired samples t-tests were used to compare the 6 composite scores (Verbal Memory, Visual Memory, Visual Motor, Reaction Time,
Impulse Control, and Symptom Score) from pre- to post-heading, with Test (pre- vs. posttest) as the independent variable and each of the 6 composite scores as dependent variables.

Header data analysis was conducted using custom LabView software. The accelerations from each header were individually analyzed and the peak of the resultant acceleration was used for analysis. The switch data were used to visually verify that the impact peak was due to the header (i.e., closely following ball-head contact), as well as verifying the directionality of the header (e.g., a “right” header should have had a peak on the right switch and no or minimal contact on the left switch). The resultant accelerations from each header direction were correlated with the neck strength in all 4 directions, using Pearson Product-Moment Correlations. For the correlational analysis, the dependent variables were neck strength (flexion, extension, and right and left lateral flexion) and peak resultant acceleration from each header direction (forward, right, and left). All statistical analyses were conducted using SPSS statistical software (v20.0, SPSS Inc., Chicago, IL). The level of significance (a) was set at 0.05, a-priori.

Results

ImPACT test results found no significant differences ($p > .05$) between pre- and postheading neurocognitive performance. Pre- and postheading composite scores, along with individual $p$-values, are presented in Table 1.

Moderate, consistent negative correlations ($r = -0.500: -0.757; p < .05$) were found for all directions of neck strength tested and resultant head acceleration in the header drills. Peak resultant acceleration and neck strength values are presented in Table 2, while bivariate correlation plots, with respective $r$- and $p$-values are presented in Figure 2.

Discussion

The key findings of this study indicate that increased neck strength was related to decreases in the magnitude of impacts during heading. Our hypothesis that neck strength would be related to header impact was confirmed. Statistically significant ($p < .05$), moderate, negative correlations ($r = -0.500: -0.757$) between isometric neck strength and resultant head impact for all three-header directions were found. This suggests that neck strength is an important variable in minimizing impact during soccer heading. In short, athletes with weaker necks cannot mitigate the accelerations to the head from the act of heading as well as athletes with stronger necks. These findings corroborate the results of Dezman et al. (4) who found that neck strength imbalance was related to increased impact during soccer heading. In addition, Viano et al. (32), found that increased neck strength lowered the magnitude of head acceleration, and thus the extent of subconcussive impacts, in football players. Furthermore, Broglio et al. (2) suggested that, not only does there need to be increased neck strength but the muscles in the neck need to be contracted at the moment of impact to help significantly decrease the effective magnitude of the impact. This assertion is corroborated by Mansell et al. (18), who found that isotonic neck strengthening alone was not sufficient to enhance the head-neck dynamic restraint mechanism. Previous research has shown that greater instant magnitude impacts are associated with increased linear and rotational acceleration (1,2,9,24). These studies have also indicated that linear and rotational acceleration may be primary predictors of head injury, suggesting that reducing the magnitude of head impacts could help attenuate the risk of head injuries.

With respect to the directional measures, there were no obvious directional relationships (e.g., neck flexion or extension strength was not substantially more related to forward headers than lateral headers), which indicated that overall neck strengthening should benefit all header types and directions.

The acute and chronic effects of subconcussive impacts on female athletes have been a major focal point of research for the past decade. This research on females is vital because previous studies have shown that female athletes are more susceptible to head injuries, while the majority of research in this area is focused on male athletes (5,30,31). In one study which examined impacts in both male and female subjects while heading a soccer ball, it was found that female athletes experienced significantly more impacts to the head than male athletes. This study suggests that female athletes should be targeted for additional head protection and strengthening measures.

Table 1 Mean ± SD of Pre- and Postheading ImPACT Composite Scores, Along with Corresponding $p$-values

<table>
<thead>
<tr>
<th>Composite Score</th>
<th>Pre-Heading</th>
<th>Postheading</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal memory</td>
<td>83.55 ± 9.48</td>
<td>88.55 ± 7.13</td>
<td>.17</td>
</tr>
<tr>
<td>Visual memory</td>
<td>73.90 ± 9.14</td>
<td>74.55 ± 12.44</td>
<td>.82</td>
</tr>
<tr>
<td>Visual motor</td>
<td>38.57 ± 5.51</td>
<td>41.87 ± 6.75</td>
<td>.17</td>
</tr>
<tr>
<td>Reaction time</td>
<td>0.636 ± 0.082</td>
<td>0.603 ± 0.043</td>
<td>.16</td>
</tr>
<tr>
<td>Impulse control</td>
<td>4.82 ± 2.89</td>
<td>6.54 ± 4.32</td>
<td>.09</td>
</tr>
<tr>
<td>Symptom score</td>
<td>5.9 ± 4.5</td>
<td>7.0 ± 6.5</td>
<td>.11</td>
</tr>
</tbody>
</table>
Table 2  Mean ± SD for Peak Resultant Accelerations from Each of the Three Header Directions and Neck Strength Values for All Four Anatomical Directions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward header peak resultant acceleration (g)</td>
<td>5.83 ± 2.23</td>
</tr>
<tr>
<td>Left header peak resultant acceleration (g)</td>
<td>6.96 ± 2.27</td>
</tr>
<tr>
<td>Right header peak resultant acceleration (g)</td>
<td>6.27 ± 2.14</td>
</tr>
<tr>
<td>Neck flexion strength (lb)</td>
<td>20.9 ± 5.7</td>
</tr>
<tr>
<td>Neck extension strength (lb)</td>
<td>25.9 ± 10.1</td>
</tr>
<tr>
<td>Neck Right lateral flexion strength (lb)</td>
<td>18.6 ± 5.5</td>
</tr>
<tr>
<td>Neck left lateral flexion strength (lb)</td>
<td>18.5 ± 5.4</td>
</tr>
</tbody>
</table>

Figure 2 — Bivariate correlation plots for each peak resultant acceleration from the three header directions and neck strength values for all 4 anatomical directions.
ball, Tierney et al. (31) found that females experienced higher head accelerations, while exhibiting less neck strength, than males. Although they did note those absolute differences, they did not find any correlation between those variables, contrary to our findings. We speculate that the differences in methodology accounted for the lack of significant correlation in their work. Specifically, they only measured linear acceleration in a forward header using a tightly controlled heading task (i.e., a JUGS machine was used to project the balls at a precise speed & distance) and they included males and females, with and without headgear, in the correlation analysis. All these factors combined can explain the differing correlation results, but the take home message is the same—women presented with lower neck strength and girth than males, and subsequently demonstrated higher impacts during heading. Similarly, Dezman et al. (4) did not find a direct relationship between header impact and isolated neck flexion or extension strength, but they used 3-dimensional motion analysis data to quantify acceleration of the skull during heading and tested male and female collegiate athletes, which can account for the differing results. Once again, although their specific findings were different from ours, they found that a strength imbalance was predictive of higher impact which supports the assertion that neck strength is important for controlling the acceleration of the head during impact.

Recent research on American football has suggested that the frequency and magnitude of subconcussive impacts may also play a pivotal role in head injuries and the long-term degradation of neurocognitive function (2,10). Previous studies have been strongly focused on determining a quantitative threshold for diagnosing individual concussive head impacts. However, few studies have looked into the effects of frequent subconcussive impacts. Our results found that the short-term neurocognitive effects of subconcussive impacts were not easily discernible, which corroborates the findings of previous papers (12,14). However, there is evidence this result may be different if looked at over a different time scale (i.e., over the course of a players career). Specifically, Matser et al. (19,20) have shown that participation in amateur and professional soccer over a career spanning years may diminish neurocognitive function. However, it was unclear whether those declines are related to the subconcussive impacts associated with heading or other factors. Recently published work by Lipton et al. (17) has found that soccer heading is associated with poorer neurocognitive performance and abnormal white matter microstructure; a relationship not explained by concussion history or demographics. Specifically, high frequency heading (defined as >885–1800 headers per year) was associated with these changes, although they suggest there is a threshold dose-response relationship. However, Lipton et al. used subject recall of header counts to establish this relationship and did not actually measure impacts specifically. It is possible that reducing the magnitude of impacts may shift this relationship to the upper end of the spectrum they suggested (e.g., perhaps 1,800+ headers would be needed before the effects are discernible), lending further rationale for the exploration of means by which to reduce the magnitude of head impacts. Future studies should aim to evaluate this relationship in the long term, monitoring the cumulative effects of frequent subconcussive impacts. This is especially important in soccer due to its worldwide popularity, the nature of the sport (i.e., athletes purposefully use their head to strike the ball), and the fact that it is predominantly played by youth athletes (i.e., only a select few play competitively into adulthood) when the brain may be more susceptible to damage.

Because changes to the way sports are played often lag behind scientific inquiry, other measures must be taken to mitigate head injuries in sports with high frequency/magnitude impacts. It has been suggested that soccer players should use protective headgear to help decrease linear and rotational acceleration of the head during impact. However, previous work has suggested headgear may not be an appropriate head injury prevention/reduction tool (31). Further, some studies have theorized that this intervention could be less salubrious than intended. While headgear may be effective in reducing fractures of the skull, there is little evidence that it mitigates concussion risk (22). In fact, it has been suggested that the introduction of helmets in sports lead to some level of risk compensation (i.e., football players using their helmet as a tool) by athletes (13,25). This possibly strengthens the argument that physiological interventions, such as mandating neck strengthening exercises, could play a significant role in reducing the magnitude of impacts to the head (3). Other potential avenues for intrinsically mitigating impact during heading should also be explored, such as the role head kinematics and neck muscle activation amplitude and timing play in reducing acceleration.

One potential limitation of this study, as with most human-subject research, was the Hawthorne Effect experienced by participants as they were being observed while they were performing the heading drills. More significantly, the heading drill was relatively low-impact (throw-in headers from 10 yards away) for safety reasons, primarily due to the age of the participants. Higher impact headers, which often happen during games, may have elicited differing results. Further, we only measured linear acceleration and did not quantify rotational acceleration, which may not demonstrate similar relationships with neck strength. As stated previously, the heading protocol could have been more tightly controlled, however we chose our protocol to more closely mirror a real-life practice scenario, as well as providing a wider range of impacts for our correlational analysis. Regardless, it is conceivable that the thrower did vary the speed of the ball between subjects which may have affected the relationships we identified, so future work should aim to monitor the ball velocity to account for this possibility. One option would be the use of a speed gun, similar to those used to track pitching speeds in baseball. Dezman et al. (4) used three-dimensional motion analysis to track the ball velocity during soccer heading using a similar throw-in protocol to ours. Unfortunately, they did
not specifically explore the effect of ball speed on the relationship between header impact/acceleration and neck strength, so it remains unknown whether this variable may have affected our results. Another identified limitation of this study was the repetition of the ImPACT test within a single day, for which validity and reliability data are unavailable. Participants demonstrated no statistically significant changes in ImPACT scores following the heading protocol, although we did note that the outcomes actually improved slightly for several of the composite scores. This may be due to an improvement in test taking proficiency, not necessarily an improvement in neurocognitive function. In short, this suggests the baseline test may not have been an accurate reflection of their actual neurocognitive abilities. Future work should conduct multiple baseline tests within a single test day, or include a control group who does not undergo heading, to provide a more accurate assessment of the effects of an acute bout of soccer heading on neurocognitive function.

While we did note significant relationships between neck strength and header impact, those relationships were only moderately strong ($r = -0.500: -0.757$). This suggests there are other factors which may explain more of the variance in header impact. For example, Dezman et al. (4) did not find a relationship between absolute directional (i.e., flexion and extension) neck strength and header impact, but did note that an imbalance of flexion and extension strength was predictive of greater header impact. Future works should aim to evaluate other potential factors, specifically: neck and trunk muscle activation and timing, head kinematics and kinetics, header “technique,” etc. Further, future studies should also aim to conduct a longitudinal evaluation which follows a bigger group of soccer players over a larger portion of their athletic career. Even though time was a limitation in our study, our findings suggest there was a relationship between impact force and neck strength; a study conducted over the course of years will be able to delve into the causal relationship between these variables. Future research should also further examine the link between subconcussive impacts and long term-health complications, such as early dementia, chronic traumatic encephalopathy, premature Alzheimer’s disease, and dyslexia. There is an alarming increase of anecdotal evidence of the cumulative effects of multiple concussions and subconcussive impacts, so an increase in sound scientific evidence of the pathoetiology of long-term neurodegenerative diseases linked to head impacts is warranted.

**Conclusion**

In conclusion, we found a moderate, negative relationship between head acceleration from heading and neck strength in female, varsity high school soccer players. This indicates that athletes with weaker necks cannot physically tolerate the headers as well as athletes with stronger necks, consistent with our hypothesis. Further, we found that there was no significant change in neurocognitive performance following our acute bout of heading. However, it is becoming evident that the cumulative effects of subconcussive impacts over time may be related to long-term cognitive degeneration, so identifying ways to minimize impacts to the head would be beneficial. Based on our findings, we propose that neck strengthening should be an important component of any head injury prevention/reduction program, especially in sports where head impacts are commonplace, such as soccer. This may be most important in the early stages of development (i.e., adolescence), when strength may not be fully developed and technique has not yet been honed by years of practice.

**Acknowledgments**

We would like to sincerely thank the administration, faculty, and students at Ossining High School for accommodating and facilitating our data collections in their Gymnasium. We would particularly like to thank Ossining High School Science Research Program Instructors Angelo Piccirillo and Valerie Holmes, varsity soccer coaches Jesse Nunes and Joe Scamarone, principal Joshua Mandel, and superintendent of the Ossining Union Free School District Dr. Phyllis Glassman.

**References**


