Several studies have noted a disconnect between the severity of a hit and the probability of concusion (Talavage et al. 2010; Guskiewicz et al. 2007). This has led to the hypothesis that repeated head impacts in contact sports may result in subconcussive damage (Guskiewicz et al. 2007), and studies have shown evidence of subconcussive damage correlated with the number of head impacts in both high school football (Breedlove et al. 2012) and hockey (Bautarian et al. 2012). While subconcussive injury appears to be very real in contact sports, the precise relationship between head impacts and its evolution is poorly understood.

In order to better understand the connection between head impacts and subconcussive injury, we instrumented the helmets of high school football players from two high schools over three seasons. Players also underwent pre-season and in-season neurocognitive testing (InFACT) and functional neuroimaging (fMRI). Changes between pre-season and in-season fMRI were then regressed against the number, location, and magnitude of all head impacts leading up to the in-season fMRI scan. Player position was also considered.

Linenmen were found to have sustained significantly more hits than skill players, but the median magnitudes of the impacts did not differ. Significant correlations between fMRI changes and head impacts were found throughout the brain. Correlations varied depending on the number of head impacts and on their magnitude, indicating that both play an important role in subconcussive injury.

**OBJECTIVES**

- Identify correlations between the number, location, and magnitude of head impacts and changes in neurocognitive trajectories.
- Determine the relative importance of subconcussive injury in head impact magnitude versus the number of head impacts.
- Examine any positional differences in the correlation between head impacts and changes in neurocognitive trajectories.

**STUDY SUBJECT RECRUITMENT**

- All procedures were approved by the Purdue IRB prior to beginning the study. Subject assent and parent consent were also obtained.
- 44 subjects were recruited from two local high school football teams that played in separate conferences.
- Subjects were recruited across three seasons from Team A, but only in season 3 from Team B.

**RESULTS**

Table 2. Head Impact Summary. Linemen experienced more overall, Facemask, and Top-Front hits (p<0.02). Magnitudes did not differ; however, both groups experienced their biggest hits in the Top Front (p<0.001).

<table>
<thead>
<tr>
<th>Number of Hits</th>
<th>Overall</th>
<th>Facemask</th>
<th>Top-Front</th>
<th>Side &amp; Back</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Mean; Median)</td>
<td>215; 330</td>
<td>184; 42</td>
<td>185; 40</td>
<td>86; 174</td>
</tr>
<tr>
<td>Percentages of Hits (Mean; Min. Ext.)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>50; 2.0</td>
</tr>
</tbody>
</table>

Table 3. Significant regressions were generated by 21 of the 116 ROIs. The variables selected by the stepwise algorithm are shown along with their partial correlation coefficient (r). C_TF*C_mMAG_TF and C_SB*C_mMAG_SB were the most frequently appearing variables. C_F did not enter in any final models. 17 of the 21 significant regressions contained a magnitude or magnitude interaction term. HS only entered 7 models and POS versus 11 in the 116 ROI models.

**CONCLUSIONS**

- The number and magnitude of head impacts as well as their interaction were all prominent in the regression results. This suggests a situation analogous to soft tissue injuries: an injury can be caused by a small number of severe loads or frequent small loads or some combination of the two.
- Expanded data set from Breedlove et al. 2012 and confirmed relationships between fMRI changes and head impacts.
- Linemen were found to experience more head impacts, but not of a different magnitude from skill positions. Position did not appear to have a strong influence on regressions. The effect of position is likely captured by differing numbers of hits.
- The spatial pattern of correlations resembles regions that experience the largest mechanical strains, which reinforces a biomechanical interpretation of these regression results.
- Regressions have excellent p-values but mediocre R-values. Additional explanatory power may be contained in angular accelerations.

**REFERENCES**


**ACKNOWLEDGEMENTS**

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**ABSTRACT**

Counting Head Impacts

Head impacts were recorded using the Head Impact Telemetry (HIT) System. Data were sorted into Facemask, Top-Front, and Side-Back helmet contact regions. For the regression analysis, the number of head impacts in each region and the median peak linear acceleration (magnitude) were assessed for each player at the time of their fMRI scan during the season.

**METHODS**

Stepwise Regression

Stepwise regression is a method for finding a good-fit model when there are too many candidate variables. A separate stepwise regression was run for 16 anatomically-derived brain regions of interest (ROIs) relating changes in fMRI for that area to the magnitude and number of hits to each of the three helmet contact regions. Interactions between number and magnitude were also considered. Player position and high school were included as covariates.

**Table 1. Variable Definitions.**

<table>
<thead>
<tr>
<th>ROI</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_TF</td>
<td>Frontal cortex (all hits)</td>
</tr>
<tr>
<td>C_SB</td>
<td>Subcortical region (all hits)</td>
</tr>
<tr>
<td>C_mMAG_TF</td>
<td>Median peak linear acceleration of all hits sustained in the frontal throughout the season</td>
</tr>
<tr>
<td>C_mMAG_SB</td>
<td>Median peak linear acceleration of all hits sustained in the subcortical throughout the season</td>
</tr>
<tr>
<td>C_TF*C_mMAG_TF</td>
<td>Frontal cortex interaction term</td>
</tr>
<tr>
<td>C_SB*C_mMAG_SB</td>
<td>Subcortical interaction term</td>
</tr>
<tr>
<td>fMRI</td>
<td>Functional magnetic resonance imaging (fMRI) detects changes in neurocognitive trajectories. The task was the N-back task, which yields very reproducible responses (Ragland et al. 2002) and is generally insensitive to alcohol and drug use (Gundersen et al. 2008).</td>
</tr>
<tr>
<td>81 in-season scans were collected from the 44 subjects.</td>
<td></td>
</tr>
</tbody>
</table>

**RESULTS**

Fig. 3. Distribution of correlated ROIs. Correlations were primarily found in the left frontal region associated with working memory and visual processing. These regions are consistent with our observation of decreased visual working memory scores on InFACT for players with changes in fMRI. The distribution is also consistent with regions that have been identified to have experienced the greatest mechanical strain during a head impact (Bazaryan et al. 2005).