

# Correlation of Head Impacts to Change in Balance Error Scoring System Scores in Division I Men's Lacrosse Players

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**Background:** Investigation into the effect of cumulative subconcussive head impacts has yielded various results in the literature, with many supporting a link to neurological deficits. Little research has been conducted on men's lacrosse and associated balance deficits from head impacts.

**Hypotheses:** (1) Athletes will commit more errors on the postseason Balance Error Scoring System (BESS) test. (2) There will be a positive correlation to change in BESS scores and head impact exposure data.

**Study Design:** Prospective longitudinal study.

**Level of Evidence:** Level 3.

**Methods:** Thirty-four Division I men's lacrosse players (age,  $19.59 \pm 1.42$  years) wore helmets instrumented with a sensor to collect head impact exposure data over the course of a competitive season. Players completed a BESS test at the start and end of the competitive season.

**Results:** The number of errors from pre- to postseason increased during the double-leg stance on foam ( $P < 0.001$ ), tandem stance on foam ( $P = 0.009$ ), total number of errors on a firm surface ( $P = 0.042$ ), and total number of errors on a foam surface ( $P = 0.007$ ). There were significant correlations only between the total errors on a foam surface and linear acceleration ( $P = 0.038$ ,  $r = 0.36$ ), head injury criteria ( $P = 0.024$ ,  $r = 0.39$ ), and Gadd Severity Index scores ( $P = 0.031$ ,  $r = 0.37$ ).

**Conclusion:** Changes in the total number of errors on a foam surface may be considered a sensitive measure to detect balance deficits associated with cumulative subconcussive head impacts sustained over the course of 1 lacrosse season, as measured by average linear acceleration, head injury criteria, and Gadd Severity Index scores. If there is microtrauma to the vestibular system due to repetitive subconcussive impacts, only an assessment that highly stresses the vestibular system may be able to detect these changes.

**Clinical Relevance:** Cumulative subconcussive impacts may result in neurocognitive dysfunction, including balance deficits, which are associated with an increased risk for injury. The development of a strategy to reduce total number of head impacts may curb the associated sequelae. Incorporation of a modified BESS test, firm surface only, may not be recommended as it may not detect changes due to repetitive impacts over the course of a competitive season.

**Keywords:** balance; accelerometers; head impacts; subconcussive impacts

Information regarding sports-related concussions continues to garner international attention. Researchers have delved into several areas, including education, sport-safety practices, rehabilitation, and objective evaluation measures. Currently, there is no single tool that can diagnose a concussion that provides

the rationale for a multifaceted approach.<sup>25</sup> One such approach involves the incorporation of an objective balance measurement. Balance disturbances are self-reported in approximately 30% of concussion cases.<sup>14,23</sup> These deficits can last up to 30 days after an initial concussion injury due to abnormal postural

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responses,<sup>33</sup> thus reinforcing the need for and incorporation of balance assessment during a concussion evaluation.

Although there is a plethora of research investigating concussions, research into the cumulative effects of subconcussive impacts is still in its infancy. A subconcussion is thought to be an underrecognized phenomenon, and is a “cranial impact that does not result in a diagnosed concussion on clinical grounds.”<sup>1</sup> It is theorized that cumulative head impacts will result in neurological deficits, including balance deficits.<sup>1,34</sup> Presently, research is mixed regarding the potential cumulative effect of repeated subconcussive impacts on neurological function, with some literature reporting neurophysiological deficits<sup>1,4,9,20,24,34,35</sup> and others finding no correlation.<sup>10,16,27</sup> Researchers have also investigated whether cumulative head impacts result in structural damage via analysis of neuroimaging, but results collected via functional magnetic resonance imaging and diffusion tensor imaging are inconclusive.<sup>4</sup>

Calculating head impact exposures (HIE) is a means of detecting subconcussive impacts. Several studies have investigated HIE, most commonly football, through instrumented helmets.<sup>8,21,26,30</sup> These studies looked to determine the average number of head impacts per practice or game, impacts by player position, linear accelerations, and/or rotational velocities/impact. Goals of these studies have ranged from determining impact frequency per athletic exposure to associating these cumulative impacts with neurocognitive deficits. Little research has been conducted on men’s lacrosse, though it is an equipment-intensive contact sport.

The purposes of this study were to investigate the difference between pre- and postseason Balance Error Scoring System (BESS) measurements on Division I men’s lacrosse players and to determine whether the differences in scores correlated with the HIE data collected via instrumented helmets during the season. We hypothesized that an increase in BESS errors at the end of the season will positively correlate with the HIE data collected.

## METHODS

### Participants

All players signed an informed consent approved by the Sacred Heart University Internal Review Board prior to beginning the study. Thirty-six Division I men’s lacrosse players (age,  $19.64 \pm 1.51$  years) from 1 university participated in this study. Two athletes were removed from this study because of a concussion (1) and an ongoing lower extremity injury (1). A total of 34 players were used for analysis (age,  $19.56 \pm 1.44$  years; height,  $71.65 \pm 2.5$  inches; weight,  $178.03 \pm 21.44$  pounds). The 34 included athletes were medically cleared at the times of pre- and postseason testing, with no restrictions.

### Instrumentation

All players wore the Warrior Sports Regulator II helmets instrumented with a GForce Tracker (GFT) sensor affixed internally to the crown of the helmet (Figure 1). The GFT contains a triaxial accelerometer and triaxial gyroscope to



Figure 1. Sensor location.

measure linear acceleration and rotational velocity, and has been shown to be a valid and reliable instrument to measure these data.<sup>7</sup> The GFT has a sampling frequency of 3 kHz and recorded data when an impact exceeded the study’s preset threshold of 20 g of linear acceleration; 40 ms of data per impact (8 ms pretrigger and 32 ms posttrigger) were recorded.

All GFTs were calibrated prior to use and after being affixed to the helmets. While being attached to a computer via USB connection, the GFTs were calibrated via the downloaded software client. To ensure proper calibration, all instrumented helmets were moved into various positions as commanded by the GFT’s software client (ie, right side, back, neutral). Once the calibration process was complete, the software client would describe the location of the sensor in the helmet. This description and the actual location of the sensor would have to match in order for the instrumented helmet to be properly calibrated.

### Procedures and Data Collection

Two evaluators performed the BESS assessments, with each evaluator assessing half the team. The same examiner assessed the same player pre- and postseason to ensure reliability. The evaluators were both certified athletic trainers with a mean 10 years ( $\pm 3.89$ ) of certified experience and both frequently use the BESS test. The intraclass correlation coefficient for interrater reliability ranged from 0.89 to 0.96 for each of the BESS subsets, computed during a preseason pilot test.

The BESS test was administered once for each player during the preseason and once during the postseason. All testing sessions were conducted on “off” days; however, we did not account for diurnal variance regarding time of day variability in our pre- and postseason data collections. Players performed the standard 3 stances (double-leg, single-leg on nondominant leg, and tandem) on 2 surfaces (tile floor and AIREX Balance Pad; AIREX) for a total of 6 conditions. For each condition, players closed their eyes, placed hands on iliac crests, and held the position for 20 seconds. Errors were calculated by the examiners and consisted of hands moving off hips, opening eyes, falling,

Table 1. Pre-and postseason BESS scores (N = 34)

BESS Stance	Preseason	Postseason	$\eta^2$
Firm double-leg	0.00 ± 0.00	0.06 ± 0.34	0.03
Firm single-leg	2.44 ± 1.73	3.09 ± 2.15	0.07
Firm tandem	1.21 ± 1.09	1.59 ± 1.52	0.10
Foam double-leg	0.03 ± 0.17	0.56 ± 0.85 <sup>a</sup>	0.32
Foam single-leg	5.79 ± 1.81	6.21 ± 2.41	0.03
Foam tandem	3.71 ± 1.59	4.71 ± 1.98 <sup>a</sup>	0.14
Total errors: firm	3.65 ± 2.52	4.74 ± 3.39 <sup>a</sup>	0.11
Total errors: foam	9.50 ± 2.65	11.44 ± 4.05 <sup>a</sup>	0.18

BESS, Balance Error Scoring System.

<sup>a</sup>Significantly more errors during the postseason assessment ( $P < 0.001$ ).

stepping, abduction or flexion of the hip beyond 30°, lifting foot off the testing surface, and/or remaining out of the proper testing position for longer than 5 seconds. The maximum number of errors allowed per condition was 10. If the player was unable to maintain the proper stance position for 5 seconds, he was awarded 10 errors for that condition. All players wore their team socks for each of the testing sessions, and all testing sessions were held in the same room at the university's athletic complex.

During the competitive season, all players wore instrumented helmets. GFTs were automatically turned on/off before and after each practice/game via a hub connected to the laptop containing the GFT software. A total of 9702 impacts over the course of 60 possible athletic exposures were documented, with an average of 29 ( $\pm 6.4$ ) athletic exposures per player for the season. An athletic exposure was defined as a session (practice or game) where players wore instrumented helmets that were turned on. The season consisted of 15 games and 45 practices where data were collected, with 6361 impacts occurring over the 45 practices and 3341 impacts over 15 games. Players did not participate in all sessions for several reasons, including injury and class schedules.

GFTs, while remaining attached to the helmet, were charged every day. After being fully charged, the data were downloaded via the hub connection and exported to a secure central server. We evaluated the following information provided by the GFT: linear acceleration, head injury criteria (HIC), and Gadd Severity Index (GSI) scores. HIC and GSI scores are injury tolerance scores and take into consideration the linear acceleration of the impact as well as the duration of the impact.<sup>12</sup>

### Statistical Analysis

A repeated-measures analysis of variance (ANOVA), with Greenhouse-Geisser correction, was conducted to determine whether there was a significant difference in the number of errors committed from pre- to postseason on the BESS tests. We

compared pre- and postseason data for the 6 BESS conditions, total number of errors, total number of errors committed on firm surface, and total number of errors committed on the foam surface. A Pearson correlation was conducted to determine whether there was a correlation between the HIE data and change in BESS scores for each of the BESS subsets as well as the total number of errors on each surface. The HIE data analyzed for each player consisted of average linear acceleration per impact, average HIC score per impact, and average GSI score per impact. All data were analyzed using SPSS (version 23; IBM Corp). Statistical significance was established a priori as  $\alpha \leq 0.05$ .

## RESULTS

Thirty-four players' data were included for analysis at the end of the season. A repeated-measures ANOVA, with Greenhouse-Geisser correction, indicated the number of errors from pre- to postseason differed significantly:  $F(3.9, 127.04) = 118.20$ ,  $P < 0.001$ ,  $\eta^2 = 0.78$ . Specifically, a significant increase in errors was found for the double-leg foam stance ( $P < 0.001$ ;  $\eta^2 = 0.32$ ), tandem foam stance ( $P = 0.027$ ;  $\eta^2 = 0.14$ ), total number of errors on firm surface ( $P = 0.047$ ;  $\eta^2 = 0.11$ ), and total number of errors on foam surface ( $P = 0.012$ ;  $\eta^2 = 0.18$ ) (Table 1). Individual analysis of the change in scores revealed 32.4% ( $n = 11$ ) of players increased their total number of errors on the postseason BESS test by 7 or more.

We calculated change in BESS scores for each of the 6 trials, total firm errors, and total foam errors and correlated this information to the HIE data. Significant correlations were found between total number of errors on a foam surface and linear acceleration ( $P = 0.038$ ;  $r = 0.36$ ), HIC ( $P = 0.024$ ;  $r = 0.39$ ), and GSI scores ( $P = 0.031$ ;  $r = 0.37$ ) (Table 2). Individual analysis of the 11 players who increased their total number of BESS errors by 7+ revealed no significant correlation with linear acceleration ( $r_s = 0.53$ ), HIC scores ( $r_s = 0.11$ ), or GSI ( $r_s = 0.23$ ). HIE data

Table 2. Change in BESS scores correlated to head impact data (*r*)

	Linear Acceleration	HIC	GSI
Firm double-leg	-0.16	-0.05	-0.06
Firm single-leg	-0.11	0.16	0.11
Firm tandem	0.15	0.09	0.12
Foam double-leg	-0.11	-0.13	-0.12
Foam single-leg	0.26	0.21	0.21
Foam tandem	0.10	0.14	0.11
Total firm errors	-0.05	0.16	0.13
Total foam errors	0.36 <sup>a</sup>	0.39 <sup>a</sup>	0.37 <sup>a</sup>
Mean ± SD	50.20 ± 7.94	33.15 ± 37.21	71.68 ± 65.65

BESS, Balance Error Scoring System; GSI, Gadd Severity Index; HIC, head injury criteria.

<sup>a</sup>Correlation is significant at the 0.05 level

are outlined in Figures 2 and 3 to illustrate linear acceleration distribution by player position, event type, and impact locations.

## DISCUSSION

Although not all postseason trials resulted in a statistically significant change in errors, it is important to note that all conditions did result in an increase in the number of errors (Table 1). These increases in errors on the postseason assessment may be related to fatigue,<sup>36,37</sup> vestibular system dysfunction,<sup>2,13,14,17,28</sup> and/or CNS deficits.<sup>18,22,33</sup> Additionally, on individual inspection, 32.4% (*n* = 11) of players committed 7 or more errors on their postseason BESS assessment. Previous studies have suggested a minimum difference of 7 errors is necessary to be considered clinically significant. Minimal detectable change scores determine whether the changes in scores are not due to variability of scoring, but rather due to postural instability.<sup>11,19,29</sup>

The changes in scores observed from pre- to postseason in athletes who did not report a concussion lends support to the suggestion of yearly baseline screenings for athletes.<sup>5</sup> However, further research investigating the carryover effect to the subsequent preseason is needed to support this theory. Having updated baseline score information will assist medical personnel in the appropriate handling of a potential concussion injury. Balance disturbances occur in approximately 30% of all concussion cases,<sup>23</sup> and dizziness is associated with 70%.<sup>13</sup> The BESS is considered a valid technique to acutely assess balance deficits associated with a potential concussion in a nonlaboratory setting<sup>3,15,31,32</sup> but may not be sensitive in detecting mild impairments or deficits greater than 3 days postconcussion.<sup>29,31</sup> The BESS was selected as the assessment tool for this study given its frequent incorporation in concussion management protocols for those in a nonlaboratory setting.<sup>3</sup>

We did find a significant correlation between the total number of errors on the foam surface and HIE data collected via GFTs placed in the helmets. A positive relationship was observed, indicating that as linear acceleration, HIC, and GSI scores increased so did the total number of errors observed on the postseason foam trials. This suggests total foam errors may be a sensitive measure to detect and monitor balance deficits associated with subconcussive impacts. A foam surface creates an unstable environment, thus placing more stress on the vestibular system. If there is microtrauma to the vestibular system, due to repetitive subconcussive impacts, only an assessment that highly stresses the vestibular system may be able to detect these changes. Incorporation of a modified BESS test, firm surface only, may not be recommended as it may not detect changes due to repetitive impacts over the course of a competitive season.

The increase in the number of errors committed on the individual trials of the BESS did not correlate to the HIE data collected. The lack of correlation may be due to a number of different factors including the short amount of time data were collected, the length of 1 competitive lacrosse season. Collecting data for consecutive seasons and then correlating to change in scores may yield different results. Another factor that may have resulted in the lack of correlation includes the concern over the sensitivity of the BESS test. Research has suggested there is a learning effect associated with the BESS<sup>6,29</sup> and that fatigue could also affect BESS scores, making this assessment insensitive to mild impairments.<sup>36,37</sup> Research also suggest that while the BESS is accurate in evaluating balance deficits acutely after a concussion, it lacks the sensitivity necessary to detect deficits 3 days postconcussion.<sup>31</sup>

The research is currently yielding mixed results regarding the potential cumulative effect of subconcussive impacts. It is theorized that repetitive subconcussive impacts may lead to neuropsychological changes, including affecting mood, cognition,

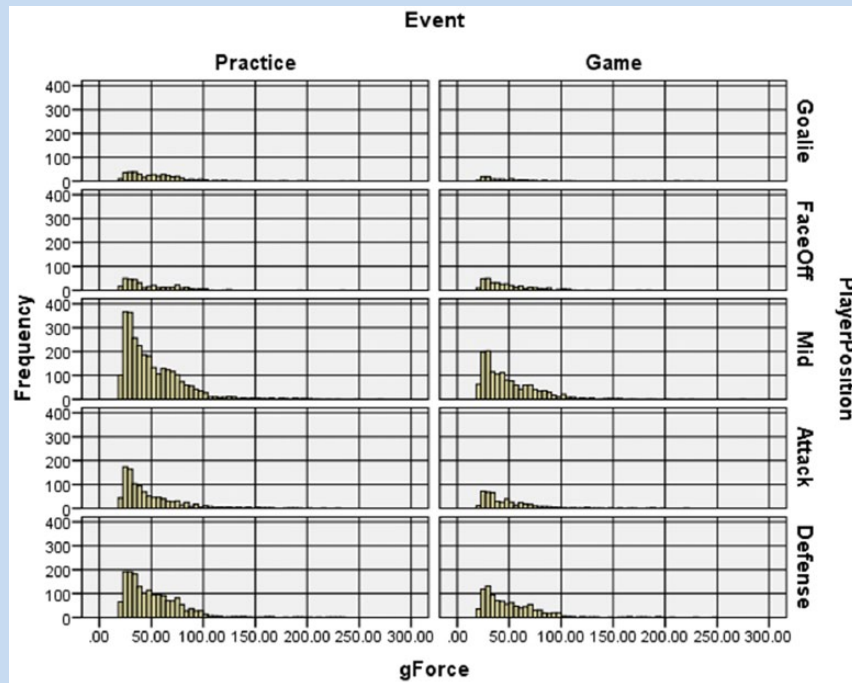


Figure 2. Linear acceleration distribution by player position and event.

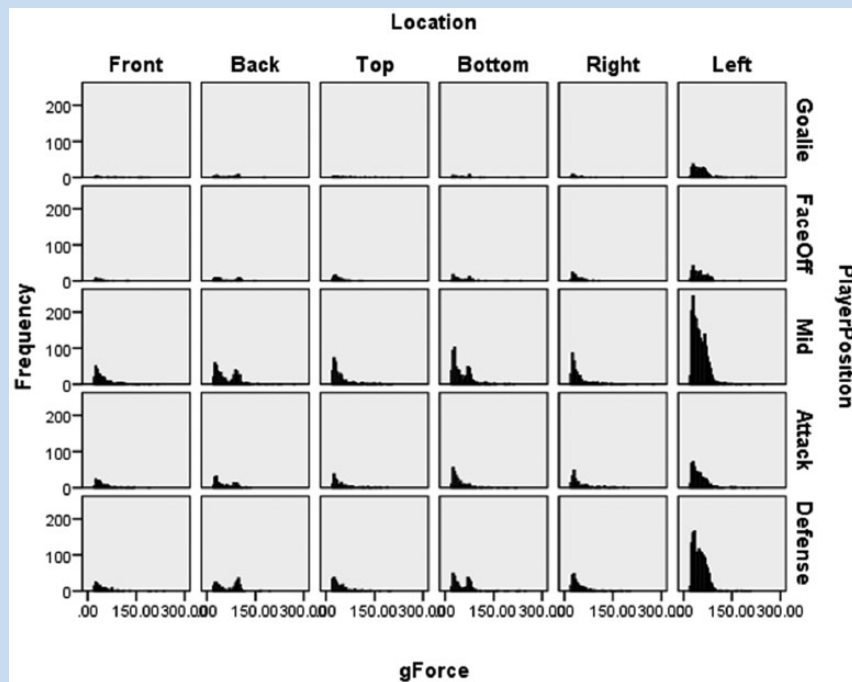


Figure 3. Linear acceleration distribution by impact location and player position.

behavior, and motor control.<sup>1,34</sup> A high number of cumulative impacts with low linear accelerations (10 g) may not result in meaningful neurological deficits, as researchers did not see changes in neurological function in collegiate football players.<sup>16</sup> However, McAllister et al<sup>24</sup> found poorer scores on a postseason cognitive test and correlated the lower scores to greater HIEs in

college athletes who did not sustain a concussion. Other researchers found similar results, linking a potential cumulative effect of subconcussive impacts to memory deficits<sup>20</sup> and neuropsychological changes in high school football players with no observed concussions.<sup>4,35</sup> The reason for variability in results may stem from the inequality of the impacts themselves. An

individual's brain tolerance to stress is unique, and subconcussive impacts will affect everyone differently. Our correlation findings suggest that cumulative head impacts result in balance deficits seen on the foam surface trials of the BESS test.

Limitations of our study include our small sample size and the lack of an instrumented BESS. The incorporation of instrumented BESS scores or the use of a force plate to assess center of pressure displacement may have provided more sensitive data. Additionally, the use to 2 evaluators to conduct BESS assessments adds concern regarding reliability. We attempted to limit this concern by ensuring the same researcher assessed the same player pre- and postseason, as well having a high intraclass correlation coefficient between evaluators. Future research investigating the potential cumulative effects of subconcussive impacts on balance should consider using a more sensitive instrument to assess sway velocity and center of mass displacements.

Monitoring the cumulative effect of subconcussive impacts has become a priority in an attempt to ensure player safety. The balance deficits observed and correlated to head impact data collected may indicate vestibular system dysfunction associated with cumulative head impacts. Objectively monitoring head impacts over the course of a season may allow for improved player safety and mitigation of long-term effects associated with cumulative head impacts.

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