SEVERITY OF HEAD IMPACTS RESULTING IN MILD TRAUMATIC BRAIN INJURY

[1]Jonathan G. Beckwith, [1]Jeffrey J. Chu, [2]Joseph J. Crisco, [4]Thomas W. McAllister, [5]Stefan M. Duma, [6]P. Gunnar Brolinson, and [1,3]Richard M. Greenwald
[1]Simbex, NH, [2]Alpert Medical School of Brown University/Rhode Island Hospital, RI, [3]Thayer School of Engineering, Dartmouth College, NH, [4]Dartmouth Medical School, NH, [5]Virginia Tech-Wake Forest Center for Injury Biomechanics, VA, [6]Edward Via College of Osteopathic Medicine, VA
email: jbeckwith@simbex.com, web: http://www.simbex.com

INTRODUCTION

In 1999, the National Institutes of Health Consensus Development Panel declared the incidence of mild traumatic brain injury (mTBI), or concussion, had reached epidemic proportions and concluded that reducing incidence, severity, and post-injury symptomology of mTBI should be a national research priority. Since that time, new evidence has been presented further suggesting a link between mTBI history and the likelihood of developing mild cognitive impairment, clinical depression, and early onset of Alzheimer's disease [1].

Sporting fields, particularly contact sports such as American-style football, are unique living laboratories for exploring human response to impact. Recently, in an attempt to determine the characteristics of head impacts leading to mTBI, the National Football League (NFL) reconstructed 31 contact events, identified through video analysis, providing impact severity measures for 25 concussive and 33 subconcussive impacts [2]. While insightful, practical constraints of laboratory reconstruction limit the scale of data collection and the ability to draw definitive conclusions.

Head Impact Telemetry (HIT) technology (Simbex, NH) was created to record the biomechanical response to impact on human subjects while participating in helmeted sports [3]. By providing historical records of impact, including those associated with mTBI, these data can be used to evaluate established injury thresholds, validate existing hypotheses, or generate new hypotheses regarding the mechanisms of brain injury. The purpose of this initial study was to examine impact severity measures obtained with the HIT System that were associated with the clinical diagnosis of mild traumatic brain injury.

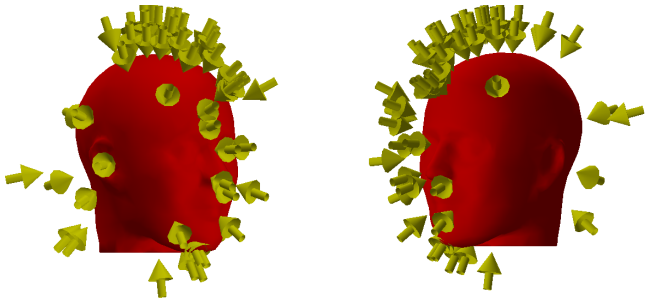

Figure 1: Location of 55 impacts recorded with the HIT System that resulted in diagnosis of mTBI

METHODS

Over a four year period, spring 2005 through fall 2008, 901 players from 8 collegiate and 6 high school football teams wore instrumented helmets during organized practices and games. Subjects were selected on a voluntary basis and included representatives from all position groups.

Helmets were equipped with an additional in-helmet unit (Riddell, OH) that positioned six single-axis accelerometers (Analog Devices, MA) against a player's head providing isolated head acceleration measures [3]. When any accelerometer exceeded a 14.4g threshold, 40 ms of data were recorded, time stamped, and processed for impact location and peak head CG linear and angular acceleration [3]. Linear acceleration time-series data were used to calculate time-weighted injury severity metrics, Gadd Severity Index (GSI) and Head Injury Criterion (HIC_{15}), used by the sports and automotive industries.

Instances of mTBI, defined as an alteration in mental status resulting from a blow to the head or body which may or may not involve loss of consciousness, were diagnosed and treated by medical staff at each institution. Each case was independently reviewed, verified, and classified using the American Academy of Neurology (AAN) grading scale. Injuries were synchronized with a single recorded impact by cross referencing the impact time-stamp with on-field reports by team personnel, and, when available, confirmed with video footage.

RESULTS AND DISCUSSION

71,390 impacts were recorded from 52 athletes diagnosed with mTBI. Three subjects sustained two injuries providing 55 recorded concussive impacts. All but 5 cases were designated as Grade 2, with symptoms resolving in less than 21 days for all but one subject (range: 15 min - 59 days). Median age, height, and weight of the concussed athletes at time of injury was 18.9 yr ± 2.3, 182 cm ± 6, and 91 kg ± 15 respectively with all position groups represented.

Average peak linear and angular acceleration for concussive impacts were 107 g ± 31and 7,079 rad/s^2 ± 3,408. HIC_{15} and GSI had a higher relative variance with mean values of 272 ± 213 and 360 ± 271, respectively. 469 subconcussive impacts (0.6%) exceeded the peak linear acceleration concussive mean, of which 25 (0.03%) had peak acceleration values greater than the highest recorded concussive impact. 51% of all concussive impacts occurred to the front of the head, 22% to the top, 20% to the side (left and right), and 7% to the back (Figure 1). While concussive impacts occurred at similar frequencies as subconcussive impacts to the top (16%) and sides (18%) of the head, the rates of subconcussive impacts to the front (38%) and back of the head (28%) were lower and higher than concussive impacts to the same locations respectively.

Two-sample t-tests ($\alpha = 0.05$) indicated linear acceleration, angular acceleration, and GSI for concussive impacts are statistically similar to values previously reported by the NFL [2], with on-field HIC_{15} values being slightly lower (Table 1). Probability curves were generated using logistic regression with the concussed player's subconcussive impacts as controls (Figure 2). Results from this analysis suggests previously reported estimates of concussion probability, based on single severity measures, are overestimated due to undersampling of subconcussive events. While it is encouraging that these findings agree with historical studies, current injury severity measures appear to not adequately predict mTBI. Further analysis is required to identify alternative measures, potentially based on individual or cumulative impact history, that improve predictive power.

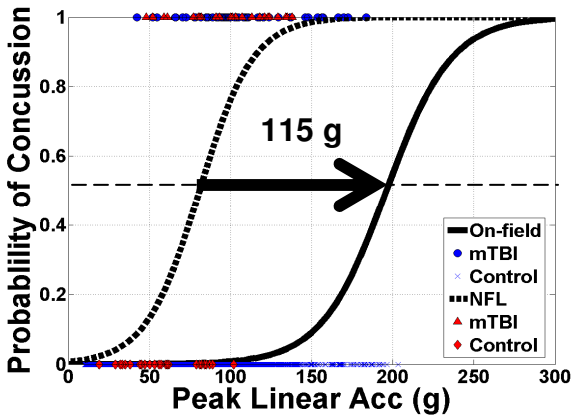

Figure 2: Probability of concussion based on peak linear acceleration. The shift in logistic regression is due to the significant number of high level accelerations that don't result in a concussion.

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Table 1: Descriptive statistics of concussive impacts recorded during competition relative to those obtained through laboratory reconstructions (* denotes $p > 0.05$).

	On-Field Measurement (n = 55)				NFL Reconstruction (n = 25)			
	Lin Acc (g)*	Ang Acc (rad/s^2)*	HIC_{15}	GSI*	Lin Acc (g)	Ang Acc (rad/s^2)	HIC_{15}	GSI
Mean	107	7,079	272	360	98	6,432	381	474
SD	31	3,408	213	271	28	1,813	197	252
Max	172	15,485	940	1,116	138	9,678	730	866
Min	42	470	21	27	48	2,615	77	94