Predicting lifetime concussion in collegiate ice-hockey players using tests of neuropsychological function and visual processing

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Introduction

Research has shown that concussions among athletes are still underreported (Harmon et al., 2013). Previously sustained concussions have been linked to an increased risk of subsequent concussions, longer recovery and poorer long-term neurocognitive prognosis (Harmon et al., 2013). Screening for lifetime concussion incidence in athletes is thus warranted. Yet currently available neurocognitive batteries used for assessment of acute concussion and in making return-to-play decisions do not reliably discriminate between healthy athletes and those with a history of previous concussion(s)(Bruce & Echemendia et al., 2009; Collie et al., 2006). There is a need for better screening tools that may be easily administered. Visual research in mTBI patients shows promise in that it demonstrates long-lasting oculomotor changes in previously concussed individuals, which can be improved through state-of-the –art technology and vision therapy (Ciuffreda and Kapoor, 2012). Oculomotor improvements have in their turn been linked to better rehabilitation outcomes in mTBI patients (Thiagarajan et al., 2011).

In the current study we followed the guidelines of an overall oculomotor-based diagnostic clinical test protocol developed for the mTBI population by Ciuffreda et al. (2011) to evaluate 43 population Division I collegiate male and female hockey players. This protocol broadly targets such oculomotor parameters as vergence (e.g. near point convergence, vergence facility, phoria, fixation disparity and stereoacuity), accommodation (e.g. accommodative amplitude and facility and version (e.g. fixational stability, saccadic accuracy and pursuit accuracy) with a particular emphasis vergence. Thiagarajan et al., 2011 note that the majority of clinical case series presented in the literature report vergence system abnormalities
following mTBI with the most common finding of convergence insufficiency, typically causing symptoms related to reading.

We then compared the sensitivity of the collected measures of visual functioning to the history of previous concussion(s) with the corresponding sensitivity of the baseline measures of neuropsychological functioning (ImPACT) to determine the former's utility in screening for lifetime concussion incidence.

Methods

Subjects:

A total of forty-two student athletes from the University of North Dakota's NCAA Division I Men's (n=21) and Women's (n=21) Hockey teams, ranging in age from 18-23, with a mean age of 20.52 participated in the study. The sample consisted of four goaltenders, 14 defensemen and 24 forwards. Seventeen athletes reported to have had at least one concussion in the past with 9 players reporting a concussion for the 12-month period preceding evaluation. The University of North Dakota Institutional Review Board (IRB) reviewed and approved the study protocol and the informed consent document. Written informed consent was obtained from each subject prior to their examination.

Instruments

Basic visual examination to determine the athlete's refractive status was conducted using a Reduced Snellen Visual Acuity chart at Near.
Oculomotor-based problems were assessed in three domains of vergence, accommodation and version. Vergence measures included vergence facility testing using the Vectograph No. 9; assessment of horizontal and vertical static fixation disparity with the Saladin Card, assessment of the athletes' dissociated nearpoint horizontal phoria using the Modified Thorington Phoria Test, measurement of horizontal and vertical disparity at far using the Distance Fixation Disparity: FFD Card test, measurement of the Nearpoint of Fixation Disparity (NPFD) and assessment of the athletes' near stereopsis with the Vectogram No. 11 Stereo Test.

Evaluaiton of accommodation involved measurement of accommodative amplitudes using the Donders push-up method, accommodative facility using +/2.00 Lens Flippers, and administration of the Convergence Insufficiency Symptom Survey (CISS), a self-report measured of convergence insufficiency.

Version measures included objective assessment of eye movements using the Visagraph II eye movement system and evaluation of coherent motion thresholds based on computerized presentations of random dot kinematograms.

Neurocognitive assessment included the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) and a self-report measure of ADHD symptomatology, the Adult Self-Report Scale (ASRS-v.1.1) Symptom Checklist.

Procedure

Upon arrival at the testing location (Valley Vision Clinic, Grand Forks, ND) informed consent was obtained from each subject followed by administration of a Z-View Aberrometer & Autorefractor (Ophthonix, Visa, Ca.) over the subject's habitual playing refraction to determine what, if any, refractive error or residual error there might be for each eye under non-cyclopleged conditions. If contact lenses were worn, the test was repeated without contact lenses and the lenses were replaced on the subject's eyes after the test was completed. The refractive outcome (uncorrected refraction or contact lens over-refraction) was then recorded for each eye along with the Aberration Index.

The athletes then completed the Convergence Insufficiency Symptom Survey (CISS) and the Adult ADHD Self-Report Scale (ASRS-v1.1) Symptom Checklist Following completion of the questionnaires, the athletes' nearpoint visual skills were assessed by a professional optometrist. The time to complete visual evaluation was approximately 30 minutes.

The ImPact Neurocognitive battery was administered to each player by their trained coaching staff before the beginning of the regular 2011-2012 season and (baseline assessment) and every time head injury was suspected. For the purposes of our study we used the most recent available ImPact data for each player (baseline player's data was used if no concussion was suspected during the regular season).

Results

Five variables were found to have significant mean differences between previously concussed and non-concussed players. These measures included accommodative facility (AF), near point of fixation disparity (NPFD), mean comprehension rate averaged over grade 5 and grade 10 material on the Visagraph test (Visagraph-C), mean duration of eye fixations averaged over grade 5 and grade 10 material on the Visagraph test (Visagraph-D) and the total score for part A of the ADHD questionnaire (see Table 1).

Examination of ROC AUCs for the 50th, 75th, and 90th, percentile showed that cutoff scores for the 75th percentile had significant ROC AUCs for NPFD, total score for part A of the ADHD questionnaire and reading comprehension (see figure 1).

The results of the analysis showed that all three variables (NPFD, Visagraph-C, and ADHD-A) were retained in the model at the final step. The model had an overall prediction accuracy of 83.3%, which was a statistically significant (χ^2 =21.58, p<0.01) improvement compared to no variables in the model (59.5%). Overall the model accounted for 54% of variability in the dependent measure (Nagelkerke R^2 = 0.54) and reached an acceptable level of discrimination according to Hosmer and Lemeshov (2000), as its overall ROC AUS was 0.70. Each individual predictor significantly contributed to the explanation of variance in the DV (see Table 2). Based on the odds ratios for individual predictors, a hockey player with the near point of fixation disparity equal to or greater than 15cm, Visagraph comprehension rate less than 85% and the total score on part A of the ADHD questionnaire equal to or greater than 11 was on average 10.72 times more likely to have had a concussion than an athletes with lower values on the NPFD and ADHD-A and a higher comprehension rate on Visagraph.

Figure 2 shows that the model had a somewhat better specificity to no concussion than sensitivity to concussion as none of the non-concussed players were erroneously identified by the model as having had a concussion in the past but 7 individuals with concussion were missed and thus classified as non-concussed. The graph also shows that 3 of the missed 7 individuals were at the border of being placed in the 'concussed' category as their probability values were around 0.50.

Table 1. Means, standard deviations, and p-values for mean differences on measures of oculomotor and neuropsychological functioning between hockey players with a history of a previous concussion and those without the history of concussion.

Measures	Lifetime Concussion (n=17)	No concussion (n=25)	*p*-Value
Visual			
Visual Acuity at Near OU (LogMAR)	-0.08 (0.06)	-0.09 (0.04)	0.46
Accommodative Amplitude (Diopters)	8.97(1.67)	9.08 (1.47)	0.82
Accommodative Facility (cpm)	8.15 (5.51)	12.04 (5.69)	0.03*
Stereopsis at near (Seconds of Arc)	26 (0.0)	26.76 (3.8)	0.41
Vergence facility (cpm)	10.65 (8.51)	12.82 (8.20)	0.41
Fixation Disparity at near horizontal (Arc Minutes; + = exo; - = eso)	+0.48 (1.50)	+0.80 (1.82)	0.54
Fixation Disparity at near vertical (Arc Minutes; + = R. Hypo; - = R. Hyper)	+0.12(0.60)	-0.20 (0.58)	0.09
Near Point of Fixation Disparity (cm)	11.76 (9.48)	5.48 (5.58)	0.01**
Phoria at near (prism diopters; + = exo; - = eso)	2.00 (4.05)	1.08 (3.67)	0.45
Coherent motion threshold average (% of dots needed to see lateral motion)	5.33 (1.80)	4.29 (1.74)	0.07
Self-Report Measures			
Convergence Insufficiency Symptom Survey	17.76 (9.09)	13.44 (9.97)	0.16
Total Score for ADHD Part A	10.24 (2.77)	7.88 (4.01)	0.04*
Total Score for ADHD Part B	16.35 (5.41)	13.40 (7.47)	0.17
IMPACT			
Total Symptom Score	3.29 (6.68)	2.79 (4.31)	0.77
Memory Composite Verbal	90.18 (8.88)	89.04 (8.44)	0.68
Memory Composite Visual	76.29 (11.75)	78.13 (11.14)	0.62
Visual Motor Speed Composite	44.62 (5.63)	41.42 (7.02)	0.13
Reaction Time Composite	0.51 (0.07)	0.54 (0.07)	0.17
Impulse Control Composite	11.12 (10.63)	11.29 (14.61)	0.97
Visagraph (averaged over grades 5 and 10 material)			
Fixations (100 words)	113.21 (31.32)	109.88 (22.02)	0.68
Regressions (100 words)	17.06 (12.95)	15.28 (9.25)	0.61
Duration of Fixations (sec)	0.25 (0.02)	0.23 (0.02)	0.02*
Reading rate with comprehension (words/min)	223.82 (56.44)	239.06 (54.00)	0.38
Grade level efficiency (Relative Efficiency = Rate (wpm)/ Fixations per 100 words + Regressions per 100 words)	9.13 (3.69)	9.68 (2.94)	0.60
Comprehension (%)	0.77 (0.07)	0.84 (0.06)	0.01**

*- significant at α=0.05; **-significant at α=0.01

Results Continued

Table 2. Logistic regression analyses summary predicting concussion in the past 12 months and lifetime concussion incidence.

Criterion	Predictors	B	SEB	Odds Ratio	ROC[a] (AUC)
Had a lifetime concussion	Visagraph: Comprehension (>=0.85%)	-2.11*	0.96	8.31	0.71*
	Near Point of Fixation Disparity (>=15.0)	2.36*	1.02	10.56	0.71*
	ADHD: Total Score Part A (>=11.0)	2.59*	1.02	13.28	0.69*

*p <0.05; Nagelkerke R^2 = 0.54
[a] Null hypothesis: true area =0.50

Figure 1. Receiver Operator Characteristic (ROC) curves for predictors, whose threshold cutoff values (>=75th percentile) showed ROC AUC values that indicated discrimination of lifetime concussion significantly better than chance at alpha=0.05.

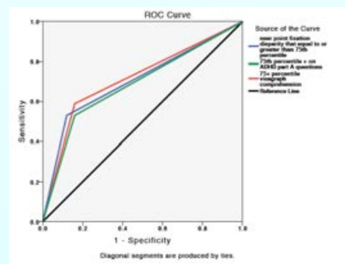
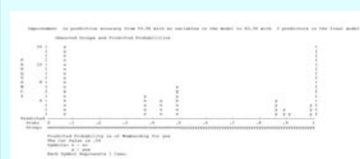


Figure 2. Observed groups and predicted probabilities of having had a concussion based on a model with 3 categorical predictors (75th percentile scores for near-point of fixation disparity, total score for part A on the ADHD questionnaire, and comprehension on the Visagraph test).



Conclusions

Overall the results of the study demonstrated that greater near-point fixation disparity, higher ADHD symptomatology and poorer reading comprehension are important in identifying individuals with a history of previous concussion(s). Specifically our model showed that a hockey player with the near point of fixation disparity equal to or greater than 15cm, Visagraph comprehension rate less than 85% and the total score on part A of the ADHD questionnaire equal to or greater than 11 was on average 10.72 times more likely to have previously suffered a concussion than an athlete with lower values on the NPFD and ADHD questionnaire and a higher comprehension rate on the Visagraph. On the other hand none of the IMPACT baseline assessment measures were significantly predictive of the individual's concussion history.

Study Limitations

One of the natural limitations of studying elite athletes is a highly circumscribed participant pool. Although we were able to test 87.5% of the target population (hockey players who appeared on the roster for the NCAA 2011-2012 season (n=42)) the number of participants was still relatively small to allow regression modeling with more than 4 predictors and was barely adequate to detect only large effect sizes. Thus some of other potentially important relationships may have been overlooked due to the lack of statistical power.

Another obvious limitation of the current study design is the correlational nature of the observed relationships. Additionally, we only recorded the NPFD break point and measured it only once. We did not measure the recovery point, which the designer feels may be even more sensitive to binocular instability than the break point (Lederer 2010). It is also recommended that the NPFD is repeated three times and that the break and recovery points are averaged. The test has not yet been standardized or normed. Investigations into test-retest reliability, intra-observer reliability of the NPFD and development of age norms for the test are currently under way.

Nevertheless, this is one of the first steps in the direction of designing better screening protocols for previously sustained concussion. Although the described model still overlooked several individuals with the lifetime concussion history, it did not misclassify any of the healthy individuals and can thus significantly improve efforts to better identify athletes more vulnerable to head trauma and neuropsychological, physical and perceptual deficits associated with it. Timely institution of rehabilitative procedures including vision therapy and sports vision training may improve the athlete's overall neuropsychological status, and improve not only sports-specific performance but possibly his/her academic performance associated with nearpoint visual skills such as reading.

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