THE EFFECTS OF FATIGUE AND INJURY ON THE KING-DEVICK TEST ACROSS A FIELD HOCKEY SEASON

by

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ABSTRACT

The King-Devick test, a relatively new vision-based assessment, has recently been incorporated into the concussion battery. However, the determinants of King-Devick testing have received limited attention in the literature thereby limiting the test's evidence-based utilization by clinicians. The purpose of this study was to evaluate potential determinants of the King-Devick test under ecologically valid conditions of collegiate student-athletes. This study was prospective longitudinal, taking place in the University of Delaware Athletic Training Room and Field Hockey field. The participants were 16 collegiate Division I field hockey student-athletes (Age: 19.5±1.0 years, Height: 165.0±6.4 cm, Weight: 61.8±5.1 kg, Previous concussions: 0.8±1.1). The King-Devick test was administered on six occasions beginning at the start of the spring 2015 season. The first testing session (T1) was administered in February and served as the overall baseline test and was the first exposure to King-Devick for all participants. The second testing session (T2) was administered at the mid-point of the season immediately after a normal practice session. The third testing session (T3) was administered post-season, within one week of the season ending. The same procedure was followed for the fall season, with a baseline test prior to the start of the season (T4), mid-season after-practice session (T5) and a post season test (T6). For repeat administration, a repeated measures ANOVA found a significant main effect for time ($P = .018$). No significant differences

were found between T1 and T2, T3, and T4. However, a simple contrast post-hoc test revealed a significant difference between baseline and T5 (P=.018) and T6 (P=.001). A multiple regression analysis measuring acute fatigue found no significant correlations between either measure of acute fatigue and K-D performance at T2 (P = .688) and T5 (P = .554). Post priori, participants were classified as false-positives in three manners; 1) any worsening from baseline (T1), 2) greater than or equal to 3 seconds worse than T1, and 3) greater than or equal to 5 seconds worse than T1 as all approaches have been utilized in the literature. Overall regarding false positives, 35.4% (28/79) of subsequent tests were slower than baseline, 17.7% (14/79) were at least 3 seconds slower than baseline, and 11.4% (9/79) were at least 5 seconds slower than baseline which were misclassified as impaired. Therefore, a 5th repeat administration of the King Devick test within a calendar year demonstrated a significant practice effect with a moderate to large effect size (0.7). Further, an exertional practice was also not associated with any changes in King-Devick test performance. However, between 31.3-68.8% of participants were misclassified as impaired on the King-Devick test despite no evidence to suspect a concussive injury. These results suggest concern in regards to specificity of the King-Devick test suggesting the possibility of false positive test results. This reiterates that a concussion is a clinical diagnosis made by a healthcare provider and supported by a multifaceted testing battery.

Chapter 1

INTRODUCTION

Due to its complex nature and common occurrence within contact sports, concussion has become a substantial concern for healthcare professionals.[1,2] It is estimated that 1.6 to 3.8 million sports-related concussions occur annually in the United States.[3-5] However, this report may be skewed since 50-80% of concussions are estimated to go unreported.[6] When comparing different sports, football has the greatest proportion and highest rate of concussions in males, while ice hockey has the highest for females.[7] Still, since player-to-player contact causes a majority of concussions, other contact sports such as men's lacrosse and ice hockey both make up a large component of concussions that take place each year.[7] Focusing specifically on women's field hockey, the concussion rate from 2009-2010 to 2013-2014 was 4.02 per 10,000 athlete exposures, with 13.3% being recurrent concussive injury.[8] Also, an NCAA self-reported concussion study in 2014 showed that women's field hockey has four times an elevated risk of sustaining a concussion when compared to sports with no increased risk for concussion, such as track and field.[8]

A concussion is defined as a mild traumatic brain injury (mTBI), composed of pathophysiological processes secondary to biomechanical forces to the head, neck or face.[9] Following an impact to the head, a metabolic cascade is initiated at the physiological level.[9] With an abrupt ionic shift, involving calcium influx and potassium efflux, the brain's functioning is off-set due to cell energy failure, coupled with the sodium-potassium (Na+-K+) pump's increased workload.[9] Therefore a demanding need for adenosine triphosphate, results in glucose "hypermetabolism", ultimately causing an energy crisis in the brain.[9]

Currently, concussion assessment includes a highly sensitive comprehensive battery of tests; however, individual tests used alone show low sensitivity for concussion diagnosis.[10,11] The most current version of the Standardized Concussion Assessment Tool (SCAT3) encompasses a self-report symptom checklist, Standardized Assessment of Concussion (SAC), Maddocks Questions measuring cognitive function, and a modified balance error scoring system (BESS).[12,13] Parts of the SCAT3 demonstrate high sensitivity for all components in concussion diagnosis.[14] However, components of the SCAT3, such as the SAC and BESS, are better tools for diagnosing rather than measuring recovery of concussion. The BESS test, although sensitive in concussion assessment, also has several drawbacks including type of sport played, history of ankle injury, ankle instability, exertion, neuromuscular balance training and fatigue as factors affecting the test.[15-19] Although these tests are highly sensitive, determinants - factors associated with these tests potentially affecting concussion diagnosis, such as learning effects - need to be identified in order for clinicians to make valid assessments.

Neurocognitive impairments, as well as deficits in postural control, are cardinal symptoms following a concussive event.[1,20] Additionally, with approximately 50% of the brain's pathways related to vision, it is also susceptible to impairment after a concussive impact; therefore the addition of a vision-based test on the current assessment battery may increase diagnostic sensitivity for clinicians.[21,22] The King-Devick (K-D) test requires eye movement, particularly saccades (rapid eye movement) attention and language function to appropriately perform the test.[21,23] The dorsolateral prefrontal cortex (DLPFC) is responsible for the eye movement and saccades required to take the K-D test.[24] Given that occulomotor – eye movement - function impairment is a key indicator of concussion, the K-D test may be a useful diagnostic tool.[25]

The K-D test is based on rapid number naming with standardized instructions for one demonstration card and three test cards.[21,23] In less than two minutes, single digit numbers are read aloud from left to right as quickly as possible, and baseline time is derived from the fastest time of two test trials without errors.[21,23] An error is defined as reading a number incorrectly, without noticing the mistake and correcting oneself immediately.[21,23] The sum of the three test card times constitutes the summary time, which also includes recorded errors.[26] A higher time indicates a worse performance. The median collegiate time for athletes ranges from 36-40 seconds.[21,26]

The K-D test is highly sensitive (1.00) and specific (.94) in its ability to identify athletes with a suspected concussion and in identifying athletes who sustained a concussive injury without being reported or witnessed; thus far, numerous sports, from the adolescent to professional level, have been used as testing populations and demonstrated that concussion inhibits K-D test performance.[21,23,25-29] Overall, those with concussion had a time increase ranging from 3 to 14 seconds, with those suffering loss of consciousness having the largest increases.[21,23,29] Although any worsening of performance is viewed as a test failure, a worsening time of 3 or 5 seconds or more is suggested as the threshold for an athlete to stop play.[25,27-30]

Currently 15 of 327 surveyed athletic trainers at multiple NCAA institutions are using the K-D test suggesting the test is currently not widely utilized.[31] In order to appropriately incorporate the K-D test into clinical practice, its determinants need to be further identified. Two significant determinants, fatigue and learning effects, are also associated with BESS and SAC.[32,33] Learning effects related to repeat administration of the K-D test show an average improvement of 2.2-5.5 seconds between testing sessions, as opposed to an improvement of 0.72-7.7 seconds in healthy individuals and 1.4-8.5 in an overall cohort (concussed and non-concussed) over a season.[21,25,27,28,30,34,35] For fatigue, a 3.6 second improvement was found in basketball players post-scrimmage, whereas after a fatiguing high intensity endurance task, times improved by a median of 1.2 seconds.[21,27] MMA and boxers were also found to have a median 1.7-1.9 second improvement on time after a 9 minute sparring round of fighting.[23,29] Although acute fatigue has not been shown to impair K-D performance, fatigue related to sleep deprivation slowed times compared to baseline.[36] While these studies evidenced determinants of the K-D test, they failed to identify repeat administration longer than a single season and did not use any measures to quantify the intensity of the exercise. Therefore, the degree of fatigue needs to be subjectively and objectively quantified to which effect takes place. Also, an evaluation of time change needs to take place to determine if a change is a result of learning effects or acute fatigue.

Recently, the effect of musculoskeletal injury on concussion tests has become a growing concern. In a study by Hutchison, athletes who suffered musculoskeletal injury performed better than concussed athletes on all neuropsychological tasks, but performed worse than the healthy control subjects.[37] This performance pattern shows that immediately after injury, impairments are observed, which raises the question of whether or not they are related to brain injury or other factors, such as fatigue and injury.[37] Two speculations arise: emotional and psychological factors that surface when an athlete is injured can, in the long term, lead to depression and anxiety which have been associated with cognitive dysfunction or orthopedic pain actually influences cognitive deficits.[37] In order to keep with sensitive assessment of the K-D test as a sideline tool for concussion, the influence of musculoskeletal injury may need to be considered to improve clinical practice and reduce potential false positives.

1.1 Purpose

As a new test being incorporated into the current concussion assessment battery, the K-D test should undergo extensive review of its determinants. As a result, the aim of this project is to further clarify the possible determinants of the K-D test by addressing these three aspects: the effect of repeat administration on K-D performance, the effect of fatigue on K-D performance, and the effect of acute musculoskeletal injury on K-D performance. Additionally, the effect of practice intensity on learning effects associated with the K-D test will also be evaluated. I hypothesize that K-D time performance will improve with repeat administration and fatigue over a season since previous studies have also demonstrated this trend in a shorter time frame. On the other hand, injury will have an opposite effect and display a worsening of performance since previous studies demonstrated impairments on cognitive tasks due to emotional and psychological issues versus orthopedic pain affecting cognitive function.

Chapter 2

METHODS

2.1 Participants

The participants in our study were 16 Division I collegiate field hockey student-athletes recruited from the University of Delaware (Age= 19.4±1.0 years, Height= 164.9±6.6 cm, Weight= 61.7±5.2 kg, Previous concussion history= 0.8±1.0). The inclusion criteria for this study were any active, healthy member of the field hockey team. Our assumption was if the individual is healthy enough to participate in their team sport then they are at risk for suffering a concussion and could be tested utilizing the K-D test. Exclusion criteria included a participant missing a testing period and self-reported factors that included: consumption of alcohol within 48 of the testing period, failure to wear corrective lens if the participant had them for the testing period, having a neurological, vestibular, or visual disorder, taking medications that could affect cognitive skills. A participant was terminated from the study if they incurred a season-ending injury, elected to drop out or chose to no longer participate on the team. The student athletes were English-speaking and ranged in age from 18-25 years. The study was approved by the Institutional Review Board (IRB) of the University of Delaware (#703862-1).

2.2 Instrumentation

The K-D test is administered to evaluate suboptimal brain function through vision testing and saccadic eye movements while also requiring attention and language function in order to perform the test properly.[23,38] The K-D is based on rapid number naming compromised of a series of 120 numbers that cannot be easily memorized.[23] (Figure 1) Standardized instructions are used with one demonstration card and three test cards; in less than two minutes, single digit numbers are read aloud from left to right as quickly as possible without making any errors.[21] Two forms of the test can be administered – test cards or an iPad application and for the purposes of this study, the iPad application was used.[25] The K-D test has a high degree of test-retest reliability (.90-.97).

This study used a Polar heart rate monitor (Polar H1 and Polar FT7) during two of the testing periods. The heart rate monitor was worn by the participants in order to provide a quantifiable measure of exertion. (Figure 2) A 15-point Borg scale with ratings from 6-20 was also used during the testing periods and the participants were asked to rate their perceived exertion to provide an added objective measure of fatigue once more. (Figure 2) With a strong positive correlation of rate of perceived exertion (RPE) to heart rate, the Borg scale has a validity coefficient of .62 , lower than previously thought (.80-.90), and a reliability value of .78, making the Borg scale a valid measure of exercise intensity.[39-41]

2.3 Procedure

Prior to the start of the participants' spring (February) and fall (August) season, after each participant provided written and oral informed consent, they were administered a baseline KD test. At each session the participants were shown a demonstration card and read 3 test cards. The testing sessions were administered in a seated position in a well lit area, either on the sideline or in an office, depending on the session. When administered on the sideline, the participant was taken aside from the activity and away from other teammates in order to minimize distractions. When given in the office, the door was shut to ensure a quiet setting to once more, minimize distractions.

The participants were tested on minimum of 6 occasions over the course of a calendar year. (Figure 3) The first test session, (**T1)** was baseline testing which occurred prior to the stat of the Spring 2015 season, in late February. Test 2 (**T2**), a within-season test, occurred in late April immediately following a normal practice session for the field hockey team. For this test date, the participants wore a heart rate monitor to track their average heart rate during practice to provide a quantifiable measure of exertion. Immediately after practice, the participant provided a self-reported rating of perceived exertion using the Borg Scale to provide a subjective measure of exertion based on their overall feeling of exertion from practice. Next, Test 3 (**T3**), a post-season test, was taken in mid-May. It was within one week of the season ending, determined as the time period when field practices were no longer taking place however the individuals were still participating in strength and conditioning programs.

Starting in the fall season the testing time periods mimicked those of the spring. Each corresponding test period was administered under the same testing conditions as previously mentioned. Test 4 (**T4**) was administered in mid-August of 2015. Following Test 4, Test 5 (**T5**) was given within season during late September, early October following a normal practice session for the field hockey team. For this test date, the participants once again wore a heart rate monitor to track their heart rate during practice to provide a quantifiable measure of exertion. Immediately after practice, the participant provided a self-reported rating of perceived exertion to provide a subjective measure of exertion. Finally, Test (**T6**), a post-season test, was given in late November, early December.

In addition to the 6 testing periods listed above, a **T**est **P**ost **I**njury (TPI) was administered if any participant suffered a non-emergency acute soft-tissue injury causing immediate removal from participation (e.g., ankle or knee sprains and muscle strains).[37] This testing was able to take place anytime after baseline testing session up until the post-season testing session and only occurred in spring (TPI(F)) and not spring (TPI(S)). The K-D testing occurred once the athletic trainer properly managed the injury and after the initial treatment was provided. Time and place of testing after the injury occurrence varied based on severity of injury and was reported descriptively at the conclusion of the study.

2.4 Data Analysis

This was a prospective longitudinal study. The independent variables in this study were the various time points of testing (T1-T6, TPI). The dependent variable waa the K-D test time, reported in seconds, which is the sum of the three tests cards with a shorter time reflecting better performance. Errors committed were recorded and presented as frequency statistics. A baseline was established by testing the athlete twice and the fastest time of the two trials, without committing any errors, was the baseline time.[23]

2.5 Statistical Analysis

The independent variable (testing time points) and dependent variable (time) were used in the statistical analysis. The first question measured the effect of repeat administration on K-D performance. A time-series analysis (i.e., repeated measures ANOVA with one group) was used with time points T1-T6 as the independent variable and K-D test time as the dependent variable. A significant main effect for time was identified and a simple contrast was conducted as a post-hoc test. The second question measured the effect of injury on the K-D performance. A dependent-samples *t*-test was used with T4-TPI(F) as the independent variables and K-D test time as the dependent variable. The third question measured the effect of acute fatigue on K-D performance. This question involved the time points T1-T2, T1-T5 and the K-D test time once more. A dependent-samples *t*-test was used for this research question.

A multiple regression analysis was also done to determine the effect of practice intensity on learning effects on the K-D test. Heart rate and Borg Exertion scores were used as predictors and the difference score (deltas) from T1-T2, T1-T5 was used.

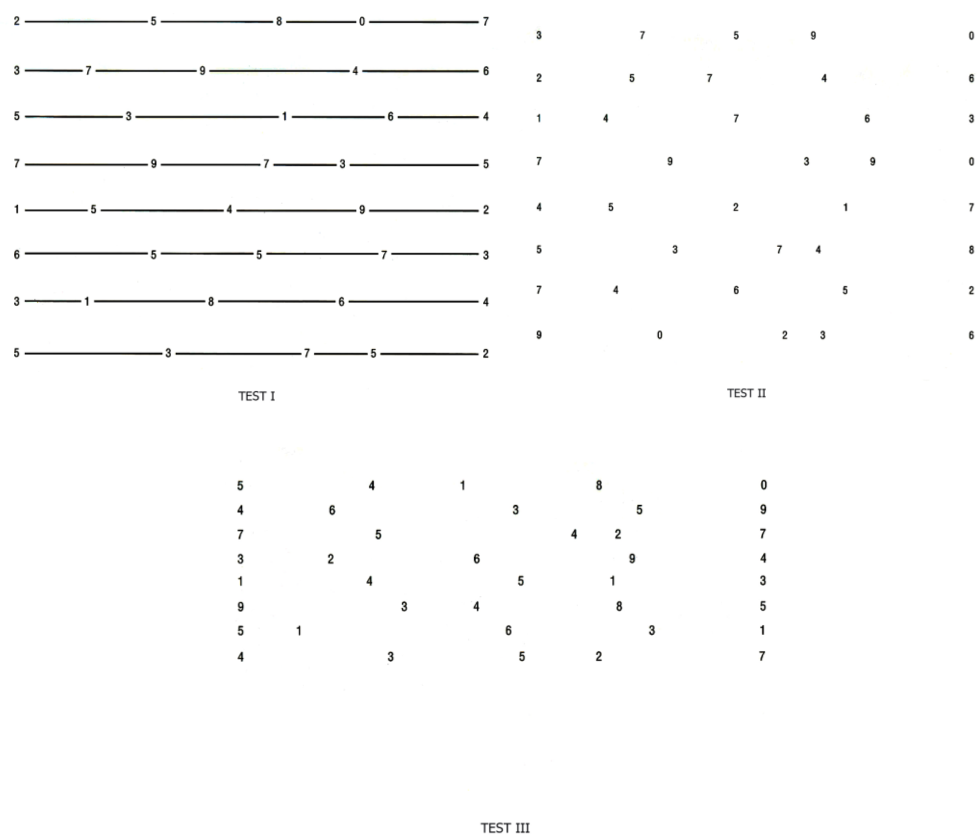

Figure 1. K-D tests cards, I-III.

Figure 2. Polar heart rate monitor and Borg scale for rate of perceived exertion.

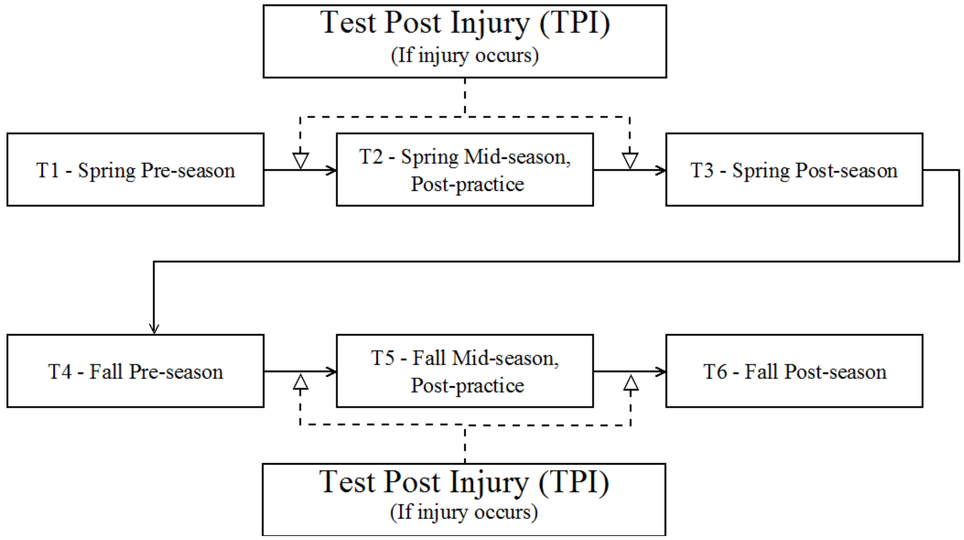

Figure 3. Time model for K-D testing time periods.

Chapter 3

RESULTS

The study initially enrolled 16 participants, but one participant missed one testing time period, therefore 15 participants completed all trials without error. (Table 1) Overall, the mean K-D time was 43.2 ± 9.9 seconds, with five participants making a total of six errors across all time points: two at T2 by the same participant and four at T3.

3.1 Repeat Administration

When measuring the effect of repeat administration on K-D performance (Figure 4), Mauchly's test indicated that the assumption of sphericity had been violated, (x^2 (14) = 34.7, $p = .002$), therefore degrees of freedom were corrected using Pillai's trace. The multivariate test, Pillai's Trace, ($F(5,10) = 4.68$, $p = .018$) showed a statistically significant effect for time. Partial Eta squared was used as a measure of effect size. Results showed a very large effect ($h^2 = 0.7$). Post-hoc comparisons revealed a significant difference between baseline (44.2 $\pm$ 8.7 seconds) and both T5 (41.7 ± 8.8seconds, $p = .018$) and T6 (41.8 ± 8.3 seconds, $p =.001$)

3.2 Acute Fatigue

According to multiple regression analysis for T2 ($r^2 = .06$, $F(2,12) = .39$, $p = .688$) and T5 ($r^2 = .09$, $F(2,13) = .62$, $p = .554$) there were no significant correlations between either measure of acute fatigue and K-D performance. (Table 2)

3.3 Acute Injury

During the fall 2015 season, only 2 acute injuries occurred, thus data for the effect of injury on K-D time was not analyzed. (Table 3)

3.4 Specificity

Specificity is the ability of a test (K-D) to correctly identify those without a condition (concussion). Specificity was evaluated in three ways: times greater than baseline, times with a change greater than 3 seconds, and times with a change greater than 5 seconds.[21,23,25-30,34] Data points from all 16 participants were utilized. When using any time greater than baseline, 11 of 16 participants had a false positive on at least one test over the course of the study (68.8%); overall the false positive rate was 28/79 (35.4%). When using any time greater than 3 seconds as a cutoff value, 7 of 16 participants had a false positive on at least one test over the course of the study (43.8%); overall the false positive rate was 14/79 (17.7%). When using any time greater than 5 seconds as a cutoff value, 5 of 16 participants had a false positive on at least one test over the course of the study (31.3%); overall the false positive rate was 9/79 (11.4%). (Figure 5)

Table 1. Testing time frame for all trials.

Testing Time Points	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
Month	February	April	May	August	September-October	November
Range Between Time Points	------	T1-T2 55 days	T2-T3 22 days	T3-T4 99 days	T4-T5 48 days	T5-T6 44 days
Range from Baseline Testing	------	55 days	76 days	174 days	221 days	265 days

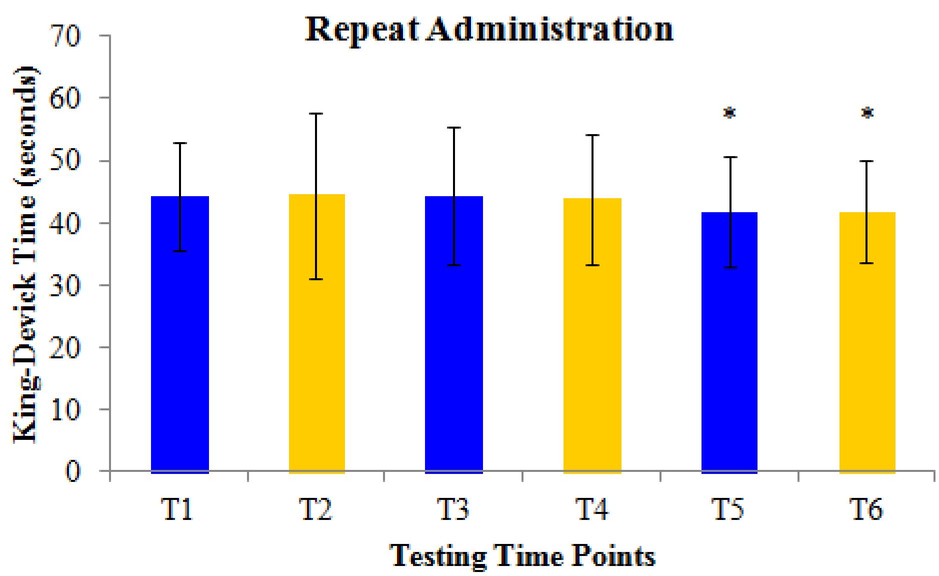

Figure 4. K-D times at baseline (T1) and each testing time point (T2-T6). Examining the effects of repeat administration, there was a significant main effect for time. Significant differences were not found when comparing T1 vs T2 (44.2 ± 8.7 and 44.4 ± 13.4, respectively; P = .914), T1 vs T3 (44.2 ± 8.7 and 44.4 ± 11.2, respectively; P = .864) and T1 vs T4 (44.2 ± 8.7 and 43.8 ± 10.4, respectively; P = .746), but post-hoc comparisons revealed the effects of repeat administration to take place for T1 vs T5 (44.2 ± 8.7 and 41.7 ± 8.8, respectively; P = .018) and T1 vs T6 (44.2 ± 8.7 and 41.8 ± 8.3, respectively; P = .001).

Table 2. Heart rate and Borg scale correlation. T2 (R^2 = .06, F(2,12) = .39, p = .688) and T5 (R^2 = .087, F(2,13) = .62, p = .554). For change in K-D time, a negative number indicates a faster time (better performance) whereas a positive number indicates a slower time (worse performance). Data for HR post-practice and Borg scale post-practice is presented with the mean ± standard deviation, followed by the range.

	T1 – T2	**T1 – T5**
Δ King-Devick time (seconds)	0.2 ± 6.1	-2.4 ± 3.6
HR post-practice (beats per minute)	148.2 ± 13.7[a] (122-164)	124.4 ± 19.5[a] (90-157)
Borg Scale post-practice (rate of perceived exertion, 6-20)	13.6 ± 1.6[b] (11-17)	11.3 ± 2.7[b] (7-16)
HR Correlation	-.229, **P = .205**	.290, **P = .138**
Borg Scale Correlation	.012, **P = .483**	.163, **P = .273**
R^2	.060	.087

[a] No significant correlation was found between baseline and fatigue testing for HR

[b] No significant correlation was found between baseline and fatigue testing for Borg scale

Table 3. Injury characteristics. Participant 71 suffered an injury to her forearm, which occurred in August before the T4 testing time period. The participant was tested within 20 minutes following the injury. Participant 40 suffered an injury to her trunk, which occurred in August before the T4 testing time period. The participant was tested within 20 minutes following the injury. Green represents times that were faster (better) than the TPI time, whereas red represents times that were slower (worse) than the TPI time. Both participants' TPI times were faster than their baseline times.

	Participant 71	**Participant 40**
Month	August	August
T1/Baseline	47.2 seconds	44.3 seconds
T2	42.8 seconds	47.3 seconds
T3	40.1 seconds	43.4 seconds
TPI	**41.0 seconds**	**35.7 seconds**
T4	39.7 seconds	39.3 seconds
T5	39.6 seconds	36.9 seconds
T6	42. 2 seconds	39.5 seconds

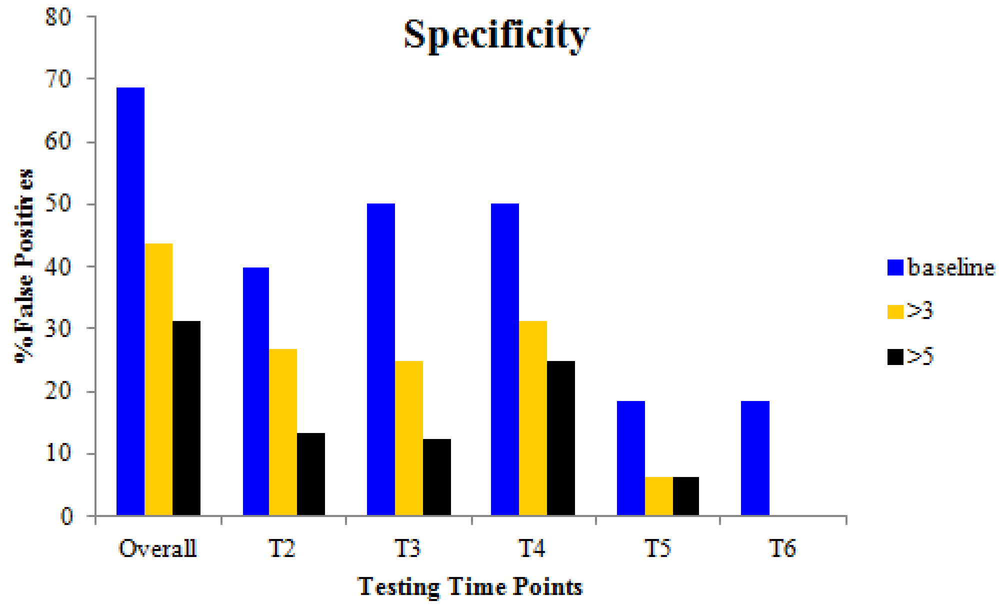

Figure 5. False positive rate for all trials. The overall false positive rate for all 16 participants is given, followed by the percent of the 16 participants that "failed" the K-D test at each time trial. The bars are not mutually exclusive: participants in the >5 seconds category are also in the >3 second category and > baseline category; those in the >3 seconds category are also in the > baseline category.

Chapter 4

DISCUSSION

The K-D test is an emerging concussion assessment tool for evaluating neurological function through vision and saccadic eye movements.[23,38] However, it is unknown how the K-D performs over the course of a full athletic season, the effect of injury, and the influence of fatigue in female collegiate athletes. Therefore, we investigated these determinants of the K-D test by addressing the effect of repeat administration, fatigue, and acute musculoskeletal injury on K-D performance. There were two main findings of this study: 1) repeat administration had a significant effect on the K-D test; however, the effect was not present until Trial 5; 2) fatigue, as measured by both heart rate and Borg scale rating, had no effect on K-D performance. Furthermore, after all data was analyzed, a significant false positive rate was revealed whereby up to (68.8%) of healthy non-concussed participants had K-D times higher than baseline. The K-D test has shown sensitivity when identifying concussion, but being aware of which factors may or may not influence K-D performance is crucial for proper interpretation of the test times, therefore aiding a clinician to make an informed clinical decision.

Improved performance associated with learning effects from repeat test administration is a determinant that exists among many concussion tests, causing a decrease in its overall sensitivity. For example, the BESS displays significant learning effects in an uninjured population, showing decreased errors as early as Day 5 post-concussion and better performance scores 30 days out and in healthy college student-athletes an improvement of 2 points was observed over the course of an athletic season.[32,42] In agreement with our hypothesis and similar to previous studies, our study showed improved performance on the K-D test likely due to the effects of repeat administration. Our study explored the effects over the course of a yearlong season (265 days including non-traditional and traditional seasons) and identified significant improvements (2.5 seconds) on the 5th administration (T5) which was 221 days from baseline and 48 days from T4. Our findings are consistent with other studies that found improvements in the performance of healthy subjects between preseason and postseason testing trials. Galetta et al. found over a year long season, a median improvement of 2.8 seconds for the overall cohort of concussed and non-concussed collegiate athletes, however there was no significant difference when comparing only healthy collegiate athletes over a season.[21] Leong found similar statistically significant findings in a collegiate football cohort, whose times improved by 1.4 seconds over a year long season.[35] On the other hand, Galetta et al. also found greater improvements in a control group of mixed youth and collegiate lacrosse players whose times, improved by 6.4 seconds post-season.[34] Similarly, King et al.in two studies with rugby players found a significant improvement of an average 7.4 seconds over 12 matches and an 8.5 second improvement across a year long season, in the overall cohorts.[27,30] Although not observed in our study, several previous studies also found better performance between baseline trial one and two associated with repeat administration, ranging from 2.2-5.5 seconds.[23-25,27,28,30,35] Overall, improved performance attributed to learning effects were not seen within the first four test administrations, but significant effects surfaced at the fifth test administration. Therefore, learning effects do not influence the K-D baseline or three follow-up test sessions, but clinicians need to be aware when identifying K-D improvements after the fifth testing session.

Current concussion clinical management incorporates a series of sideline tests; however when testing the athlete, it is likely that he or she is fatigued from participation.[12] However, a problem arises since separating neurological deficits from fatigue can be difficult, especially since maximal exercise has shown to both limit and facilitate cognitive function.[43] K-D performance and fatigue has been measured previously, however, fatigue was not quantified - all participants were tested immediately post-exercise and stated what the physically fatiguing activity was (e.g., pre- and post-basketball scrimmage), but showed no actual measure of the cohort's fatigue. Herein, heart rates (HR) ranged from 90-164, and Borg scale scores ranged from 7-17, for both T2 and T5. When comparing HR and Borg scale scores for T2 to T5, T2 had a higher overall HR (148.20 ± 13.68 and 124.38 ± 19.50) and Borg scale score (13.60 ± 1.64 and 11.25 ± 2.70). Contrary to our hypothesis, acute fatigue, quantified by either HR or Borg measures, was not a significant predictor of K-D performance at T2 or T5 (44.4 ± 13.48 and 41.67 ± 8.84). K-D test performance has been seen to improve after a 2-2.5 hour basketball scrimmage by a median of 1.0 second and 3.6 seconds.[21,35] In boxers and MMA fighters who performed a three round, nine minute sparring session and were "physically fatigued" still performed significantly better; one study showed improvements by a median 1.9 seconds, and the other showed no significant difference after the fatiguing match. Lastly, a rugby league used a modified repeat high intensity endurance test, a series of six 70-meter sprints in a 20-meter grid, as a fatiguing task and after being fatigued, a median improvement of 1.2 seconds was witnessed.[28] Unlike the improvements seen across multiple cohorts, when quantifying our participants' fatigue, their performance did not improve after an exertional practice session. This information is valuable determinant for the practicing clinician and suggests participation related fatigue would not be the cause of an individual "failing" a KD testing.

Injury occurrence was limited (N=2) during the season and therefore was not statistically measured in this study. Acute musculoskeletal injury can exhibit a degree of cognitive impairments, as measured by computerized neuropsychological testing, with a proposed explanation being attributed to emotional and psychological factors or previous vulnerabilities associated with injury, rather than pain from the injury itself.[37] Two non-emergency acute soft tissue injuries occurred over the course of the season. Participant 71 suffered an injury to the forearm and was tested ~20 minutes after her injury was sustained. Compared to all of the testing time points, the participant's TPI time (41.0 seconds) was faster than half of the previous times and simultaneously worse than the other half of the times. Participant 40 suffered an injury to the trunk and was also tested ~20 minutes after sustaining the injury. Compared to prior testing time points, the participant's TPI time (35.7 seconds) was faster than all prior times.

We hypothesized that injury would result in a slower time; however both participants were faster than their T1 baseline times (7.4 seconds). However, future research is needed to delve further into the relationships of injury and K-D test performance.

Specificity, also known as the false positive rate, measures the proportion of negatives (those without a condition) that are correctly identified as such.[45] It is clinically important because multiple participants (N=11) were classified as "failing" the K-D test, although they had suffered no head trauma and were not suspected of having a concussion. The K-D test is designed to identify or "rule-in" concussions and typically, if an athlete has a suspected concussion, the test is administered once on the sideline. According to the K-D test scoring, if the subject performs slower (worse) or has increased errors compared to his or her baseline, the athlete is evaluated further for injury; if the time is faster (better) with no errors compared to his or her baseline, the time becomes the athlete's new baseline. If this protocol was followed, 65% of all of our testing time points would have "failed" whereas all of our 16 participants (100%) would have been classified as failing. The threshold of "times greater than baseline" is the current guideline utilized for determining a "failing" K-D test.[21,23,26,29,30,34] Applying this threshold to our participants, 68.8% (11/16) were classified as "failing" at least one test time point. Other thresholds have been proposed including – >3 seconds[25,27,28] and >5 seconds[29] since an average worsening on K-D performance after concussion was 5 seconds.[24,25,29] Utilizing the >3 second threshold, nearly half (43.8%; 7/16) failed at least one test; using most conservative approach of a >5 second threshold almost one third failed (31.3%, 5/16) "failed".

Although the groups are not mutually exclusive (if a participant had a time greater than 5 seconds, they were also in the greater than 3 seconds group and greater than baseline group) this is a substantial number of false-positives since over half would have been considered concussed. According to our results, the K-D fails to accurately identify non-concussed participants as having no concussion; instead it categorizes (31.3%-68.8%) of participants as potentially concussed. Since same day return to play is not feasible and is discouraged by the current concussion position and consensus statements, it is crucial to make the correct decision as to whether an athlete is concussed or not to prevent misdiagnosis and provide the best care for the athlete.[13,44] However, it is unknown what the sensitivity and specificity of the K-D test is between 0-5 second threshold cut-off values.

The K-D test does not differ from other contemporary tools being used to diagnose a concussion including the graded symptom checklist, SAC, ImPACT, BESS, and SOT tests which have sensitivity and specificity limitations; a fact that reiterates the need for a multifaceted assessment battery. No single test should stand alone in the evaluation of a concussion since no single "gold standard" test rises above the rest.[10,13,44] A concussion is a medical decision based on clinical judgment.[13] However, focus can stray from making an informed medical decision and rely on simply "checking the boxes"; but a checkbox system does not apply to all concussions since they are different for each athlete.[45] Nonetheless, each test plays its crucial role in detecting impairments to form a clinical diagnosis. Specificity of the current concussion battery consisting of self-report symptoms, computerized neurocognitive assessment and balance assessment reaches 97.5%; on the other hand, sensitivity -or true positive/false negative, measures the proportion of positives (those with a condition) that are correctly identified as such - reaches 80%, although others have found it to be higher (89-96%).[10,46] Without attaining 100% sensitivity and specificity, athletic trainers and other healthcare providers continue to use the multifaceted battery because it is the best tool thus far and currently recommended by the SCAT-3.

4.1 Limitations

This study was limited to a small cohort of NCAA Division I collegiate female field hockey student-athletes and therefore the results should not be generalized to other populations. Furthermore, there was no control group of concussed participants for the healthy testing time points to be compared to, thus specificity could not be calculated. Lastly, the iPad version rather than the flash card version of the K-D test was the chosen way to administer the test to the participants. King et al found that those without concussive injury who used the iPad application had slower baseline.[25] Average baseline times were found to be 36-40 seconds, whereas 44.2 seconds was the average baseline time for our study.[21,26]

4.2 Conclusion

The main findings of this study were that repeat administration has an effect on K-D test performance; however not until the fifth test administration and acute fatigue does not affect KD performance. A secondary finding of this study was a poor specificity with 31.3-68.8% of participants “failing” the test at least once during the study. As a new and emerging test, the K-D test could fill the gap for the current need of vision-based test in the current concussion assessment battery. With poor oculomotor function serving as a robust indicator of concussion, the K-D would seem suitable to incorporate into baseline testing so it can be used on the sideline when evaluating concussion.[25] However, the K-D is not a perfect test and, as evidenced by this study, and possesses several limitations. Still, concussion is and always will be a medical decision, made based on clinical judgement.[13]

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Appendix A

LITERATURE REVIEW

A concussion is defined as a mild traumatic brain injury (mTBI) comprised of pathophysiological processes.[1] It occurs from forces that are applied directly or indirectly to the skull, leading to rapid acceleration and deceleration of the brain.[2] A growing substantial concern has developed among healthcare professionals and physicians since concussions are a highly individualized injury which may have a subtle presentation, but are also complex to diagnose and treat.[3,4]

It is estimated that 1.6 to 3.8 million sports-related concussions occur annually in the United States.[5] When comparing different sports at the collegiate level, football was found to have the greatest number of concussions, while men's wrestling had the highest rate, followed by men's and women's ice hockey.[6] Player-to-player contact causes a majority of concussions and overall, competition concussion rate bypasses the practice concussion rate.[6] However, level of competition is debated when it comes to concussion rate. Shankar observed a trend of increased concussion rate with increased level of competition, under the assumption that the stronger and more skilled the players, the higher the risk of injury.[7] Conversely, Guskiewicz found a higher concussion incidence rate among the high school setting compared to the collegiate setting, attributed to a greater number of players being exposed to potential injury.[8] Focusing specifically on women's field hockey, the concussion rate from 2009-2010 to 2013-2014 was 4.02 per 10,000 athlete exposures, with 13.3% being recurrent concussive injury.[6] Also, an NCAA self-reported concussion study in 2014 showed that women's field hockey has four times an elevated risk of sustaining a concussion when compared to sports with no increased risk for concussion. No matter the setting or sport, every concussion that takes place is serious and needs to be diagnosed and treated properly.

Gender also plays a role in the rate of concussions as female athletes have an overall higher concussion rate than males in sex-comparable sports at the collegiate and high school levels (women's soccer, women's basketball, and softball).[6] Several reasons have been postulated to support this gender difference including: motor control associations, as women have greater angular rotation and head-neck segment peak acceleration and displacement, biomechanical differences such as weaker neck musculature and greater ball-to-head ratio among female soccer players.[6,9] Higher reporting rates in females have also been discovered - they are 43% more likely to report symptoms than males, however, this trend does not follow suit post-concussion.[10] Interestingly, cultural explanations also attributed to the gender difference, with the United States being generally more protective of female athletes opposed to male athletes.[9] This could lead to athletic trainers, coaches and parents treating head injuries in female athletes more seriously, delaying return to play, whereas their male counterparts may be encouraged to play despite injury or to ignore reporting an injury.[9] Male or female, healthcare professionals need to be aware of the risks that both genders are exposed to when playing their sport.

After a concussion occurs, a cascade of ionic, metabolic and physiologic events occur.[11] Immediately following the injury, excitatory neurotransmitters, such as glutamate, are released along with other ions, specifically the efflux of potassium and the influx of calcium.[11] With the efflux of potassium, neuronal suppression takes place, potentially causing loss of consciousness and amnesia.[11] Simultaneously, calcium influx lead cell energy failure, which happens at an increased rate due to reductions in magnesium levels.[11] With an abrupt ionic shift, the sodium-potassium (Na+-K+) pump increases its workload, with a demanding need for adenosine triphosphate (ATP) causing an increased glucose metabolism, in order to return to homestasis.[11] This “hypermetabolism”, coupled with decreased cerebral blood flow, leads to an energy crisis in the brain.[11] This energy crisis is worsened when the process of mitochondrial oxidative metabolism is not able to be completed due to hyperglycolysis – a lack of ATP sends a second stimulus for increased glycolysis resulting in heightened levels of lactate leading to acidosis, membrane damage, alterations in blood brain barrier permeability and cerebral edema.[11] Once the initial period of hyperglycolysis occurs, cerebral glucose metabolism is diminished within 24 hours of sustaining the concussion, but may last for 2-4 weeks.[11] It has also been noted that a 7-10 day window of cerebral vulnerability exists several days after a concussion due to the aforementioned impairment of cellular metabolism. As a result, a safe and gradual return to play program is crucial. However, when utilizing a symptom-free waiting period before returning athletes to play, the rate of repeat concussion was significantly higher (6.49%) than those without a symptom-free waiting period (0.90%).[12]

A concussion is a multifaceted injury producing both short-term and long-term symptoms. An athlete can present with a number of symptoms after sustaining a concussion, but no two concussions are alike and each varies by individual. The short term symptoms can be divided into three major categories although multiple other symptom categories exist: physical (headache, dizziness), cognitive (feeling in a "fog", difficulty concentrating), and behavioral (emotional and sleep disturbances).[3] If cognitive or balance issues are not present, athletic trainers and other medical staff can only rely on self-reported symptoms; however, self-report symptoms are limited by the athlete's honesty.[13] Unreported concussions have become a problem, but encouragingly it has been found that the unreported concussion rate has decreased from the previous rate in high school athletes of 50-75% to 11.8% in collegiate athletes.[13,14] Of the 11.8% unreported concussions, 57.9% are attributed to collegiate female athletes; on the other hand, 26.1% of concussions are unrecognized and are comprised of male athletes (57.1%).[13] A drastic change in this rate has been attributed to the increased media attention for concussions, potentially increasing athlete's awareness of symptomatology and future health complications associated with concussion.[13]

Immediately following a concussion, it is imperative that healthcare professionals take all precautions to avoid second impact syndrome (SIS). It is important to note there is a lack of evidence proving the existence of SIS and evidence is based solely on anecdotal case reports.[15] If it does exist, this phenomenon occurs when an athlete with an initial head injury, typically concussion, sustains a second head injury before the symptoms of the first have been cleared.[15] A single impact results in increased cerebral blood volume followed by cerebral swelling, secondary to the loss of cerebral vascular autoregulation.[15] Regardless of its existence, it is crucial to understand that any post-concussive symptoms could lead to further health complications and athletes should not return to play too soon so ultimately a fatal outcome does not ensue.[11,15]

On the other hand, it is important to think about not just the next impact to the head, but also multiple future impacts to the head and how they could affect an athlete later in life. Concussive and sub-concussive trauma is thought to be a primary risk factor for chronic traumatic encephalopathy (CTE).[16,17-19] CTE is a progressive neurodegenerative disease that has been found in former collision-sport athletes and may involve dispersed occasions of axonal injury, previously set in motion by an initial concussion and provoked by successive traumatic injuries.[17-19] Under normal conditions, tau is associated with microtubules in axons in the brain and poses no risk; however trauma causes dissociation of tau leading to disfigured forms resulting in neurotoxicity.[19] Clinically, the disease is associated with symptoms of irritability, impulsivity, aggression, depression, short-term memory loss and heightened suidicality.[18] Although using biased sampling, a study by McKee found evidence of CTE in 80% of 85 individuals with a history of repetitive mild traumatic brain injury.[19] Most of those with CTE were athletes of various sports such as football, ice hockey, boxing and wrestling, though several military veterans were also identified. [19] The results are thought-provoking, though since this disease can only be found in brains of the deceased, future research needs to be directed toward potential early-life identifiers.

A concussion happens suddenly, yet it can have life-long effects. For most (80-90%), a concussion resolves within a 7-10 day period.[20,21] However, persistent symptoms lasting greater than ten days are reported in 10-15%.[20] Whether mild or severe, concussions can cause long-lasting consequences, ranging from physical, cognitive, behavioral and emotional.[22] Research has found mTBI, especially repeated episodes of concussion (≥ 3), to be a risk factor for earlier onset neurodegenerative diseases such as Alzheimer's disease (AD), along with psychiatric disorders such as clinically diagnosed depression.[23] Risk for AD is 2.3-4.5 times more likely for those that suffered an mTBI compared to those who have not, based on severity of the head injury.[22] In fact, severity of head injury is correlated with the magnitude of AD and loss of consciousness (LOC) at the time of injury approximately doubles the associated risk of AD.[23] Mild cognitive impairment (MCI) is a form of cognitive decline and memory problems and has been found to increase the risk in retired football players who have been subject to three or more concussions.[23] Furthermore, depression is also prevalent in retired football players who have had not a single concussion, but cumulative concussive events (≥ 3).[24] With multiple diseases occurring later in life associated with concussions that have happened earlier in life, prevention, early recognition and proper care is imperative.

Immediately after a concussive event occurs, a thorough evaluation should be administered to aid in early recognition. Since the effects of concussion are not confined to one domain, a multifaceted approach is used including the following areas: self-report symptoms using a checklist, postural stability, mental status using the Standardized Assessment of Concussion (SAC), and computerized neurocognitive testing, one being the Immediate Post-Concussion Assessment and Testing (ImPACT).[2, 3] Nevertheless, with a concussion comes the most challenging question among healthcare professionals: when should the athlete be allowed to return to play (RTP)?[17] The Fourth International Conference on Concussion in Sport developed a general guideline to follow for an RTP protocol, including an initial period of no activity, followed by light aerobic exercise once symptom-free, sport specific exercise, noncontact training drills, full-contact practice and finally return to play.[20] On the other hand, it is widely accepted that the RTP protocol should be individualized to each concussed athlete, in conjunction with the symptom checklist, cognitive exams and balance testing.[25] Since research is still ongoing and concussions present in different ways, clinicians should utilize the individual approach toward RTP and base decisions on the signs and symptoms of the concussed athlete and not grouped into a classification of management protocols.[2]

Self-reported symptoms are an obvious way to assess an athlete's concussion and the presence of concussion-related signs and symptoms serve as a contraindication for RTP.[26] A graded-symptom checklist (GSC) simply provides a list of concussion-related symptoms and allows the athlete to check yes (presence of symptom) or no (not present) for each and frequently has a component allowing the athlete to rate the severity (0 [no symptoms] – 6 [severe]) of each symptom.[26] The GSC has been seen with 17-29 items and has generally categorized its items into four areas: cognitive, somatic, emotional, and sleep problems.[27] The 17-item and 20-item GSC are commonly used and have been identified as very sensitive (.89) and specific (1.00) for detecting concussion amongst athletes.[21,27,28] Given that initial evidence shows the validity of self-report checklists, the continuous development of checklists has surpassed the investigation into their validity, sensitivity, specificity, and reliability.[26,29] With any symptom checklist being used, it has been found that symptom scores have changed depending on intensity of exercise, therefore making their interpretation for sports concussion problematic.[27] Also, evidence has shown that cognitive deficits are present and extend beyond the time frame of an athlete reporting they are symptom-free, thus heeding the use of a symptom checklist in conjunction with other assessment tools.[21,28] Unfortunately, symptom checklists require patient honesty and vary by each individuals "state" independent of injury making it difficult to rely on them alone.

Since the GSC is a subjective measure of concussion-related signs and symptoms and should not be used alone when assessing a concussion, clinicians use an objective cognitive test, such as a SAC.[30] The SAC, containing measures of orientation, immediate memory, concentration and delayed recall, is meant to give athletic trainers the ability to determine not only the presence, but also the severity of neurocognitive impairments.[21,28,30,31] A perfect SAC score is 30 and McCrea found that the average healthy score is 27, with an average change of about 4 points post-concussion.[21,28,30,31] The SAC has been found to have a relatively high peak sensitivity (.80) at the time of injury and a high specificity (.89-.98) through day 7 demonstrating its ability to identify concussion.[21,28,31] The SAC is also clinically valid and reliable in detecting mental status changes in concussed athletes since multiple studies have demonstrated concussed scores significantly lower than nonconcussed.[21,26,30,31] It is found to be convenient for sideline use and age and education have no effect on SAC performance.[30] Conversely, learning effects have been found with typical SAC recovery within two days due to those effects, proving its insensitivity of identifying concussion recovery and explaining the need for more testing tools.[21,28,31]

Besides traditional written cognitive testing, such as the SAC, ImPACT program is a commonly used neurocognitive computerized test. ImPACT consists of four sections of tests, including attention, memory, processing speed and reaction time.[32] The tests provide four composite scores in verbal memory, visual memory, visuomotor speed, and reaction time.[32] Each section's score is a weighted score of combined scores from different testing parts – for example, visual memory's score is an average of the X's and O's section along with the Design Memory section to make the total score. Higher scores for verbal memory and visual memory indicate better performance as opposed to lower scores for visuomotor speed and reaction time are better. Visual motor processing speed and reaction time have been found to be the most reliable, as verbal and visual memory were the least reliable.[33,34] ImPACT, when including signs and symptoms, has been found to be highly sensitive (.82) and specific (.89) in detecting concussion, but more so sensitive when identifying concussed individuals versus misclassifying healthy athletes as having impairments (predictive likelihood). [34] Two studies found that ImPACT misclassified 46% of healthy individuals as concussed, most commonly in the categories of verbal memory and reaction time.[33,34] ImPACT also has problems involving "sandbagging" or intentionally performing poorly on the test and a study by Erdal found it to be difficult for athletes (11% successful) to do so since the test uses invalidity criteria.[34,35] Unfortunately, moderate learning effects have been recognized and the commonplace baseline group testing has exhibited extraneous error, negatively affecting performance.[34,36] No test alone is perfect, which is why the ImPACT is used in combination with other tests in multifaceted battery.

Another cognitive assessment tool used frequently on sidelines is the Sports Concussion Assessment Tool (SCAT).[37] The most current and revised version is the SCAT3, but SCAT2 is still used and comparable.[37] The SCAT is used for immediate post-trauma screening of athletes, including a 22-item symptom checklist, Glasgow Coma Scale, Maddocks Questions, SAC, brief coordination test, and a modified Balance Error Scoring System (BESS) test.[37] The score can range anywhere from 0-100 points with lower scores resulting in a poorer performance. A large study of NCAA Division II athletes used the SCAT2 to determine the average total score to be 91 points in healthy individuals.[37] To identify the sensitivity and reliability of the test, each component of the SCAT was evaluated separately.[38] The task of obtaining a baseline measure for a large number of athletes is time-consuming and has become a downfall of the SCAT.[37] Also, since parts of the SCAT have exhibited learning effects, it can be assumed that the SCAT encompasses learning effects as well. Gender differences as well as differences between those athletes with and without prior concussion history are also present during each test component.[29] The SCAT and all of its components make it practical and useful as a concussion assessment tool.[38] One component of the SCAT, the Maddocks Questions, is a set of questions used to assess orientation and is a crucial piece of the SCAT.[39] Asking questions relating to recall of recent events, such as details of the game, are more sensitive than standardized orientation questions in detecting concussion; however there has been limited study concerning this topic.[39] The SCAT is a great component of the multifaceted testing battery, incorporating multiple elements into one testing tool.

Since the same areas of the brain that display neurocognitive deficiencies are also responsible for maintaining postural equilibrium, extensive testing for postural stability needs to take place.[40] The Balance Error Scoring System (BESS) was a test developed to identify postural insufficiencies and consists of three stances: double-leg stance (hands on hips and feet together), single-leg stance (standing on non-dominant leg, hands on hips), and tandem stance in heel-toe fashion (non-dominant foot behind dominant foot) on a firm and foam surface.[41] Typically, errors are counted and added together for each stance, with a maximum score of 10 for any stance and a total score of 60, with a higher total score being worse.[42] A study by Iverson found the normative value for people aged 20-29 was roughly 11, while the normal range is between 8 and

14.[43] The test-retest reliability of the BESS test has been found to be moderate to high in youth and young adults (.64-.70).[44,45] On the other hand, BESS has a relatively low sensitivity which is highest at the time of injury (.34) and a high specificity (.91-.97) across multiple time points throughout injury.[28,46] Although the BESS can detect a concussion without the use of other assessment instruments and it becomes more sensitive when used in combination with other tools, it has several drawbacks.[42] BESS performance has been found to be influenced by several factors including type of sport played, history of ankle injuries, ankle instability, exertion, fatigue and testing environment.[47-49] On the other hand, BESS has shown high-content validity identifying balance problems in concussed and fatigued athletes and those with functional ankle instability, ankle bracing, aging populations, and those completing neuromuscular training.[41] After repeat administration, BESS reveals significant learning effects, improving scores, and neuromuscular balance training programs also show reduced errors.[45,50] Therefore, BESS should not be used alone and only in association with other concussion tools of the multifaceted battery.

As part of the vestibulospinal system, balance is disrupted after a concussion, but a second part of the vestibular system, the vestibulo-ocular system, which maintains visual stability during head movements, is also disrupted. [51] Vestibulo-ocular function is not evaluated in the current tools used for concussion assessment, but the Vestibular/Ocular Motor Screening (VOMS) assesses the five domains: smooth pursuit, horizontal and vertical saccades, convergence, horizontal vestibular ocular reflex, and visual motion sensitivity. The VOMS demonstrates high sensitivity in recognizing athletes with a sport-related concussion and also shows internal consistency and validity when compared with the post-concussion symptom scale between healthy and concussed athletes.[51] However, there are limited studies to date and research is still needed to test if VOMS has the ability to predict concussion recovery and detect impairments across time with repeat administration. Since concussion management is continually evolving, the VOMS may help target those with unresolved dizziness, balance, and other vestibule-ocular impairments who would need a referral for vestibular rehabilitation.[51]

It is important to note that several factors affect cognition other than concussion, one of those being exercise.[52] Concussion has primarily been viewed as an injury accompanied by cognitive disturbance; however, it has become known as a physiological insult to the brain, encompassing changes in cerebral blood flow (CBF) and autonomic nervous system dysfunction.[52] Emerging data suggests that exercise improves brain function especially in neuronal function as well as the regulation of CBF, whose irregularity is the main reason for worsening symptoms and their reappearance.[52] Although exercise is part of the return to play protocol, exercise also affects some aspects of neurocognitive function negatively. A VO_2 max treadmill test in one study showed decreases in immediate and delayed memory recall supposedly stemming from fatigue, while cerebral oxygenation and cerebral cortex activity are also decreased.[53] In another study, an ergometer cycling test showed that perceptual discrimination decreased along with increases in vigilance tests that required working-memory processes.[54] Though these findings may seem unsettling, they provide a way to gauge athlete's return to sport so it is not too soon and not too late.

Interestingly, another facet other than exercise influences cognition: musculoskeletal injury.[55] In a study comparing a concussion group, injury group, and healthy group, the concussed athletes had the lowest means scores of all of the neurocognitive tasks, while the injury group did slightly better, but worse than the healthy group.[55] This consistent pattern of performance showed that athletes with musculoskeletal injuries also displayed a decline in test performance immediately after injury and raises the question that neurocognitive impairments after concussion may be related to other factors, or in combination with, brain injury.[55] Two speculations arise: emotional and psychological factors that surface when an athlete is injured can, in the long term, lead to depression and anxiety which have been associated with cognitive dysfunction or orthopedic pain actually influences cognitive deficits.[55] Athletic trainers and healthcare professionals need to keep this information in mind when using a multifaceted battery in order to accurately diagnose a concussion.

Overall, no two concussions are created equal since athletes all present differently. One may have cognitive impairments, while another has unresolved balance issues. Therefore, it is important to assess each athlete with the full battery of concussion tests, ranging from symptom checklists and cognitive tests to visual and balance testing. The complexity of the injury can be accompanied by misdiagnosis; therefore a tool to quickly and accurately diagnose them is warranted. The multiple assessment tools that are currently used cover an array of deficits. However, vision is also frequently affected and a vision-based test would increase diagnostic power for clinicians.[56] With several sideline tools failing to accurately diagnose concussions, it is imperative that new tests be examined.[56] Given that poor oculomotor function is a robust indicator of an mTBI, the King-Devick test (K-D) is a potential tool to assess vision.[57]

The K-D test is based on rapid number naming compromised of a series of 120 numbers that cannot be easily memorized.[58] Standardized instructions are used with one demonstration card and three test cards; in less than two minutes, single digit numbers are read aloud from left to right as quickly as possible without making any errors.[59] An error is defined as reading a number incorrectly, without noticing the mistake and correcting oneself immediately. A baseline time is established by testing the athlete twice and the fastest time of the two trials, without error, is the baseline time.[58] The sum of the three test cards times constitutes the summary time and errors are also recorded.[59] A higher time indicates a worse performance. Two forms of the test can be administered: test cards or an iPad application.[56] Currently, one study by King recognized those without concussive injury that used the iPad as having slower baseline times compared to those using the test cards.[57] It requires eye movement, particularly saccades; attention and language function are also necessary in order to perform properly.[58]

So why and how does reading numbers rapidly in the K-D test relate to concussion and brain function? The K-D test requires the planning and execution of saccades - rapid eye movements between points of fixation, not synonymous with reading - which involves widely distributed brain pathways, involving the frontal eye fields, supplementary eye field, dorsolateral prefrontal cortex (DLPFC), parietal lobes, and the brainstem.[58,60] Saccades can be triggered reflexively by the parietal eye fields, showing crucial DLPFC involvement, or intentionally by the frontal eye fields.[60] The intricacy and distribution of this network significantly increases its susceptibility to neurological insufficiencies and axonal injury associated with concussion.[58] The DLPFC, the highest cortical region of the brain, is responsible for motor planning and working memory with a link to anticipatory saccades, an eye movement required for the K-D test.[60] The DLPFC's main functions include: inhibition of reflexive saccades to a target (anti-saccades), anticipatory saccades, and short-term spatial memory.[60] It has been suggested that the DLPFC's location in the frontal region of the brain leaves it more susceptible to injury from concussion, however, there is little information regarding this topic.[60] In cases of suspected concussion, an assessment of saccades with a rapid sideline test is important.[60] The K-D test requires saccades to perform which can also be used to evaluate other cognitive domains - attention, working memory, along with spatial and temporal orientation.[60] One study linked eye movement dysfunction to athletes with post-concussive syndrome (PCS), where symptoms linger for longer than usual after the initial injury. A discovery of additional dysfunctions in other cognitive domains such as decision-making under time pressure, short-term spatial memory, visual attention and subcortical brain function was found showing athletes with PCS do not follow normal recovery of eye movements.[61] Therefore, visions relationship to high cognitive functioning, concussion compromising that function, and the multiple pathways in the brain devoted to afferent and efferent vision, the K-D test may help reveal incomplete recovery of brain function.[62]

The original design of the K-D test was to act as a predictive tool to detect reading difficulties in children and it is now finding its way into other realms of the medical community for disorder and disease research.[63] Because visual dysfunction is a primary disability associated with multiple sclerosis (MS), the role of the K-D test as a visual performance measure in MS patients is being examined.[63] A study by Moster found that the K-D test distinguished MS patients from healthy controls even accounting for age difference, with an average difference of 13.5 seconds between the groups.[63] It can also account for fatigue in patients since fatigue related to MS represents a different pathological state.[63] Another disease commonly affected by ocular abnormalities, specifically abnormal visual scanning, saccadic eye movement impairment, and deficiency in eye movement planning and target anticipation, is Parkinson's disease (PD).[64] A study by Lin compared PD patients with essential tremor (ET) control subjects and found that after adjusting for age and gender, PD patients had a higher (worse) time by an average of 10 seconds.[64] The K-D test provides a brief quantitative way to check visual function, while being portable and easy to use.[63,64] K-D has also been implemented to investigate other disorders such as sleep deprivation and hypoxia-induced cognitive impairment.[65,66] Sleep deprivation negatively impacts neurocognition, including diminished attention and slowed visuomotor response.[65] Visual function is not affected by game-related fatigue according to K-D performance; however, fatigue associated with sleep deprivation slows saccadic velocity which in turn increases spontaneous blinking, and reduces accuracy for smooth pursuit.[65] A study with residents on call showed that those not taking call had a 3.8 second improvement on the K-D test from baseline, consistent with learning effects, while a 0.23 second slowing of time was recorded for those residents post-call, negating the learning effect.[65]

Along with testing sleep deprivation and K-D, hypoxia-induced cognitive impairment is another disorder that uses the test. High altitude reduces oxygen supply to the central nervous system due to hypoxia from reduced partial pressure of oxygen.[66] Cognitive function decreases in these conditions, specifically above 10,000-12,000 feet, placing risks for those on high altitude flights or climbing terrain at great heights.[66] The first study to use the K-D test to note affects on altitude tested its subjects at three time points: normoxia (normal breathing), hypoxia, and post-hypoxia where considerable changes were noted when tested in the hypoxic condition.[66] A change from a 46.3 second baseline to 54.5 seconds hypoxic condition demonstrates an altered cognitive performance using the K-D test.[66] Clearly the K-D test has shown its validity and success in detecting cognitive deficits in several areas of the medical community, posing a potential use in other areas where cognitive deficits need to be measured.

Presently, the K-D test has used numerous sports as test populations from adolescents to the professional level including football, men's and women's soccer, boxing, men's and women's basketball, men's ice hockey, MMA fighting, rugby, women's lacrosse, and women's volleyball.[56-60,67,68] The median time for collegiate athletes is 36-40 seconds.[56,59] Following concussion, an average worsening of five seconds (3.1-7.9 seconds) was a distinguishing characteristic of athletes compared with baseline times.[57,60,67] It has been suggested that five seconds may be a useful cutoff time, but currently, any worsening from baseline is considered failure of the test.[56,66] It has been also found that some athletes with a concussion return to or improve upon their baseline time after 14 days and almost all return by day 21.[69]

The K-D test has a high degree of test-retest reliability (.97) and is highly sensitive (1.00) and specific (.94).[56,59,67] However, Silverberg found that K-D sensitivity decreased within hours in an emergency room cohort with the absence of baseline data.[70] It has the ability to identify athletes with a suspected concussion and can also identify athletes who have sustained a concussive injury but was not witnessed or reported, since times show a change in performance.[58] ImPACT and SAC test correlations with the K-D test supports the validity of the test as one that requires visual function.[57,71] Test performance is not altered according to age, education or concussion history as reported by a study with professional hockey players.[72] Another study supported this finding, showing no influence of age or gender on the K-D test.[73] Overall, reference values across several age groups were comparable – high school athletes (13-18 years) have the fastest overall median time of 32-34 seconds whereas the collegiate median time is 37.9 and the professional median is 40 seconds.[74] The K-D test does exhibit learning effects since athletes at the collegiate and professional level have been found overall to have an average improvement of 2.2-5.5 seconds between first and second baseline testing sessions.[60,75] In addition, several studies have seen lower post-season times when compared to pre-season times, with changes ranging from .72-7.7 seconds in healthy subjects and 1.4-8.5 seconds in the overall cohort, concussed and non-concussed.[57,59,68,69,75,76]

Several studies have found that concussion inhibits performance of the K-D test.[57,59,60,67,68] One study involving collegiate football, men's and women's soccer and basketball reported that sideline K-D times for the concussed were significantly lower than baseline times, supporting the sensitivity of the K-D test to the harmful effects of concussion on visual tracking.[59] Times increased by a median of 5.9 seconds after sustaining a concussion, along with increased errors, recorded manually, potentially due to the tradeoff of accuracy versus increased time.[59] It is important to note this change was greater than the average worsening of five seconds. Other studies involving collegiate and youth cohorts also found similar results, with median changes of 4.4 seconds and an average change of 5.2 seconds from baseline to post-injury.[68,76] Two studies whose participants were amateur boxers and MMA fighters both found that post-fight times for K-D were lower than the original baseline times.[58,67] The single boxer who sustained a concussion had a 3.2 second difference in time compared to his baseline, showing a lesser change opposed to the average five second worsening in the collegiate cohort.[58] The MMA fighters who sustained head trauma had median worsening of time by 11.1 seconds; not surprisingly, those who suffered from LOC had an even more prominent median worsening of times by 18.0 seconds.[26,67] When investigating K-D in a rugby population, it was found that of the seven concussed players performed worse with changes in times averaging between 1.2-7 seconds.[57,69,75] Similarly, in a cohort of professional ice hockey players, two concussed individuals showed changes of 4.2 and 6.4 from baseline to post-injury.[60] The specific changes in times may vary by sport, but they all display a central theme: concussion shows a worsening on K-D performance.

Although the K-D test is sensitive to detecting concussions, a complex injury needs to incorporate a multifaceted approach with the use of a combination of tests. A few studies with amateur rugby and professional ice hockey players used the K-D test in association with the aforementioned SCAT2. Research presented by a study using rugby players saw no significant correlation between the SCAT2 and K-D test.[75] On the other hand, a study using professional ice hockey players found a significant correlation between the SAC component of the SCAT2, leading to every 1 point reduction in SAC score resulting in a 2.2 second decline in K-D time.[60] Yet another study with collegiate football and women's lacrosse and soccer found that K-D test increases were associated with the worsening of the SAC and BESS.[56] Together, the SAC and K-D test captured 89% of concussed athletes, whereas the BESS and K-D captured nearly 100% of individuals with a suspected concussion.[59] However, another study found that the K-D test was related to the Limits of Stability (LOS) balance test based on faster movement velocity of the LOS resulting in better performance on the K-D test; no relationship was found for BESS or any other LOS characteristics.[74] This signifies that although some relationships were found, the K-D test captures a different construct not measured specifically in the SCAT2, BESS or LOS.[74]

It has been previously noted that fatigue from prolonged bouts of physical exertion as well as injury cause declines in cognitive performance.[54,55] However, the effects of fatigue may be related to the task performed and time of post-exercise testing.[54] In relation to the K-D test, it has been found that acute fatigue alters test performance with times improving as opposed to worsening.[58,59,67,68] Two studies using a cohort of boxers and MMA fighters found that those who did not sustain noticeable head trauma and were determined to have signs of physical fatigue and exhaustion did not demonstrate a worsening of time for the K-D post-fight test; in fact, they improved by an average of 1.7-1.9 seconds.[58,67] Another study found athletes who participated in an intense two hour basketball scrimmage also showed no worsening of K-D time.[59] A 3.6 second improvement was observed, showing consistency with learning effects.[59] Notably, the test was administered at the end of the team's season, suggesting that fatigue over the course of a season did not affect their performance.[59] As opposed to using sport performance as a measure of fatigue, rugby players were exposed to a fatiguing task, specifically the repeat high intensity endurance test (RHIET) involving a series of six 70-meter sprints in a 20-meter grid.[77] Post-exercise and baseline performance on K-D were significant, with K-D times improving after exercise by an average of 1.2 seconds (0.1-3.9).[77] These improvements in performance suggest that exercise either enhanced players' capacity regarding reading speed or were attributed to learning effects; a worsening could be attributable to a neurological dysfunction stemming from a concussion.[77]

A concussion is a complex injury affecting various brain functions. Proper management and care of such an injury is crucial so effects do not resonate with an athlete later in life. With a multifaceted battery of tests in place, recovery and return to play are closely monitored. However, with new and emerging research, newer tests, such as the K-D, can be added to the current battery to enhance concussion diagnosis and prevent further injury to the brain. For that reason, the K-D test is a reliable and valid addition to sideline testing for determining optimal brain function. Nevertheless, the continuous search to improve the identification of concussive injury with various tests reiterates that a concussion is a clinical diagnosis made by a healthcare provider, supported by the multifaceted testing battery.

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Appendix B

IRB DOCUMENTS

UNIVERSITY OF DELAWARE

RESEARCH OFFICE

210 Hullihen Hall
University of Delaware
Newark, Delaware 19716-1551
Ph: 302/831-2136
Fax: 302/831-2828

DATE: January 28, 2015

TO: Lauren Kriebel
FROM: University of Delaware IRB

STUDY TITLE: [703862-1] The Effects of Fatigue and Injury on the King Devick Test across a Field Hockey Season

SUBMISSION TYPE: New Project

ACTION: APPROVED
APPROVAL DATE: January 28, 2015
EXPIRATION DATE: January 27, 2016
REVIEW TYPE: Expedited Review

REVIEW CATEGORY: Expedited review category # *(4)*

Thank you for your submission of New Project materials for this research study. The University of Delaware IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the study and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the study via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

Please note that any revision to previously approved materials must be approved by this office prior to initiation. Please use the appropriate revision forms for this procedure.

All SERIOUS and UNEXPECTED adverse events must be reported to this office. Please use the appropriate adverse event forms for this procedure. All sponsor reporting requirements should also be followed.

Please report all NON-COMPLIANCE issues or COMPLAINTS regarding this study to this office.

Please note that all research records must be retained for a minimum of three years.

Based on the risks, this project requires Continuing Review by this office on an annual basis. Please use the appropriate renewal forms for this procedure.

If you have any questions, please contact Nicole Farnese-McFarlane at (302) 831-1119 or nicolefm@udel.edu. Please include your study title and reference number in all correspondence with this office.

RESEARCH OFFICE

210 Hullihen Hall
University of Delaware
Newark, Delaware 19716-1551
Ph: 302/831-2136
Fax: 302/831-2828

DATE:	January 4, 2016
TO:	Lauren Kriebel
FROM:	University of Delaware IRB
STUDY TITLE:	[703862-2] The Effects of Fatigue and Injury on the King Devick Test across a Field Hockey Season
SUBMISSION TYPE:	Continuing Review/Progress Report
ACTION:	Approved for Data Analysis Only
APPROVAL DATE:	January 4, 2016
EXPIRATION DATE:	January 27, 2017
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # *(4)*

Thank you for your submission of Continuing Review/Progress Report materials for this research study. The University of Delaware IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

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If you have any questions, please contact Nicole Farnese-McFarlane at (302) 831-1119 or nicolefm@udel.edu. Please include your study title and reference number in all correspondence with this office.

Appendix C

DATA COLLECTION FORMS/QUESTIONNAIRES

Effects of Fatigue and Injury on the King Devick Test across a Field Hockey Season

Health History Questionnaire

Please answer the following questions as honestly as possible. <u>Your answers will remain confidential and will NOT be shared with your coaches or athletic training staff</u>

Subject ID: ____________________ Date: _____ / _____ / _______

Age: _______ Gender: M F

Height: _______ Weight: _______

Year in School: FR SO JR SR 5th

Please answer the following questions about your injury history;

1. Have you ever suffered a concussion? YES NO
   - If Yes, When was your last concussion? ________
   - If Yes, how many concussions have you suffered? _________
   - If Yes, how long were you out before you returned to play? _________

2. Do you have any on-going injuries? YES NO
   - If Yes, what and when did it occur? ______________________________
   ____
   - If Yes, are you currently participating? YES NO

3. Have you sustained an injury in the past 6 months? YES NO
   - If Yes, when and what? ______________________________
   ____
   ____
   - If Yes, how long before you returned to play? ______________________
   ____

4. Do you have any known neurological disorders? YES NO
   - If Yes, please explain: ______________________________

5. Are you currently taking any medication which affects your cognitive skills (thinking)? YES NO

6. Have you ever been hit in the head and "knocked silly" or "seen stars" YES NO
   If Yes, how many times has this happened? ________

7. Have you ever been knocked unconscious or lost your memory after getting hit in the head? YES NO
   If Yes, how many times has this happened? ________

8. Do you have corrective lens/eyewear? YES NO
   If Yes, are you currently wearing them? ________

9. Have you consumed alcohol in the last 48 hours? YES NO