

THE EFFECT OF READING DIRECTION AND HISTORY OF MULTIPLE CONCUSSIONS  
ON THE KING-DEVICK TEST

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## INTRODUCTION

Traumatic brain injuries (TBIs) account for 1.1 million emergency room visits, 235,000 hospitalizations, and 50,000 deaths per year; many of these injuries are categorized as mild TBIs, particularly sports-related concussions (SRCs).<sup>4</sup> It is estimated that between 1.6 and 3.8 million SRCs occur annually in the United States.<sup>4-6</sup> This number may be low since many concussions go unrecognized due to avoidance of, as well as lack of access to, medical care.<sup>4</sup> In recent years, there has been growing concern regarding the long-term physical, cognitive, and emotional consequences of concussions.<sup>4</sup> For example, concussions are associated with an increased risk of depression, epilepsy, substance abuse, dementia and other neurodegenerative diseases, and even death.<sup>4,7-9</sup> Furthermore, the “invisible disability,” which can be defined as when a person does not outwardly appear to have deficiencies that have resulted from sustaining a concussion, costs over \$60 billion every year.<sup>4</sup>

It is important to note that an individual who prematurely returns to their normal activities after sustaining a concussion is at a greater risk for protracted recovery.<sup>7,10</sup> Returning too early may also put them at risk for developing second impact syndrome (SIS).<sup>7,10,11</sup> Early recognition of concussion improves outcomes by preventing patients from suffering further neurologic injury.<sup>7</sup> However, there are several limitations of the current concussion diagnostic methods. First, there is a reliance on subjective symptom scales and balance assessments.<sup>1,12</sup> Second, some assessments have poor inter-rater reliability (e.g., Balance Error Scoring System [BESS] Test, Vestibular/Oculomotor Motor Screening [VOMS], Immediate Post-concussion Assessment and Cognitive Testing [ImPACT]) and are not one hundred percent sensitive or specific.<sup>11,13-18</sup> Third, multiple tests must be used in conjunction because no single diagnostic method assesses each system (i.e., visual processing, oculomotor function, balance control, memory, attention) that can be affected by a concussion.<sup>5</sup> This can be a rather time-consuming process and can be difficult for a clinician to perform on a sideline of a sporting event. Fourth, due to the heterogenous nature of concussions such that signs and symptoms vary among

individuals and depend on which portion(s) of the brain have been damaged, current screening methods often fail to catch deficiencies that may or may not present in every person.<sup>1,11</sup> Finally, performance on concussion assessments can be confounded by various baseline factors such as age, sleep deprivation, and gender.<sup>19,20</sup>

Visual processing engages approximately half of the brain's circuits, thus concussed individuals often experience visual dysfunction.<sup>12</sup> Therefore, it is important to take advantage of the objectivity, reliability, and ease of use of the King-Devick Test (KDT), a neuro-ophthalmologic function examination that can help clinicians assess concussions and monitor patient recovery.<sup>12</sup> The KDT is a timed assessment during which individuals read aloud three pages of single digit numbers, from left-to-right and top-to-bottom, as fast and as accurately as possible.<sup>1,7</sup> The KDT assesses an individual's attention, language function, and saccadic eye movements, which are regulated by several different portions of the brain. Previous research has shown that the KDT is 86% sensitive and 90% specific with regard to concussion detection.<sup>1</sup> A recent investigation showed that the KDT with the addition of the Standard Assessment of Concussion (SAC) captured abnormalities in 89% of concussion individuals, whereas the combination of the KDT, the SAC, and BESS identified 100% of concussed athletes.<sup>21</sup> However, there is a major limitation of the KDT in that it can be affected by various external factors including age, gender, sleep deprivation, and whether the test was administered in an individual's native language.<sup>3,19,20</sup>

Based upon previous research, non-native English speakers face an additional cognitive component when performing the KDT.<sup>2,3</sup> No research has been done that investigates whether, and if so, how, the reading direction affects an individual's performance on the KDT. Therefore, the purpose of this study is to investigate if fluent English speakers, both with and without a history of concussion, perform worse while performing a reverse version of the KDT (reverse-KDT; reading the digits from right-to-left and bottom-to-top) due to the higher cognitive load of the reverse-KDT compared to the traditional reading direction. It is hypothesized that performing

the reverse-KDT will result in worse performance (I.e., longer test times), and that the history of concussion group will perform worse than the group with no history of concussion.

## METHODS

### *Participants*

This cross-sectional study included 71 participants divided into the following groups: a history of concussion (HxC) and no concussion history (NoHx). The group assignments were based off the participant-provided health information on the initial questionnaire. All participants were between 18 and 26 years old, fluent English speakers, and enrolled as Indiana University Bloomington students. Exclusion criteria for all groups were proficient fluency of any language that reads right-to-left or top-to-bottom and right-to-left, any visual, ocular, or brain injury within the past 12 months, history of eye movement disorder, uncorrected visual impairment, or a diagnosis of attention deficit/hyperactivity disorder, attention deficit disorder, dyslexia, dyscalculia, or any language processing disorder.

### *Procedures*

Participants were first asked to complete a questionnaire, which collected demographic data as well as other pertinent data such as concussion history, ocular/visual injury/disorder history, and any learning disability diagnoses. Based on the concussion history provided in the initial questionnaire, subjects were assigned to either Group NoHx (no concussion history) or Group HxC (history of concussion). Participants were randomized into one of two KDT formats: traditional (left-to-right) KDT or reverse (right-to-left) KDT, based on the R randomization function. The researcher explained the procedure by saying, "This test evaluates your saccadic eye movements, or rapid eye movements from one fixation point to the next. This test is comprised of three test cards. Each test card has eight lines of several digits (numbers). Please read the digits aloud as quickly but as accurately as possible from [traditional: "left-to-right and top-to-bottom"; reverse: "right-to-left and bottom-to-top"]. If you make a mistake, correct it if

you can and continue. This is a timed test—tapping the tablet screen starts and stops the stopwatch. You will have a brief break in between cards to catch your breath. Each test progressively increases in difficulty. The horizontal lines guiding you from digit to digit on Test Card 1 disappear on Test Card 2. The lines of digits on Test Card 3 are closer together than they were on Test Card 2. Do you have any questions?”

The researcher then started the app and brought up the demonstration card. Participants completed the demonstration card according to the instructions given. Participants were reminded to “read the digits as quickly but accurately as possible” and in the direction according to their assigned test condition before beginning the test. The researcher silently counted any errors while the subject completed the test, one card at a time. The participants could take a brief (generally 1-5 seconds) pause after tapping the screen to stop the timer and can then tap again to start the timer for the next card. At the conclusion of the test, the researcher recorded the total time and number of errors on the data collection sheet. The participants then completed the test a second time, following the same instructions. The total time and number of errors for the second attempt were also recorded. The actual data collection took approximately six minutes, with the initial questionnaire taking an additional three minutes to complete; the total duration was less than ten minutes.

### *Instrumentation*

The King-Devick Test (KDT) is a common component of sideline concussion evaluations, and is a timed assessment of saccades, or quick movements of the eyes between two points. During the test, an individual reads three pages of single-digit numbers from left-to-right, top-to-bottom, as quickly and accurately as possible. The KDT has high levels of test-retest reliability, especially in the absence of concussion.<sup>1,7</sup>

The Reverse King-Devick Test (Reverse-KDT) is a timed assessment during which an individual reads three pages of single-digit numbers from right-to-left, bottom-to-top, as quickly and accurately as possible.

The Karolinska Sleepiness Scale measures the perceived level of sleepiness as experienced by each individual subject. Recent research has indicated that increased levels of sleepiness correlate to decreased performance (increased time) on the KDT.<sup>20</sup>

### *Statistical Analysis*

Demographic variables were compared between groups and test conditions using independent t-tests for continuous variables (age, hours of sleep, Karolinska sleepiness scale score) and chi-square tests for categorical variables (gender, degree-in-progress, and ethnicity). The two total times for the KDT assessments were averaged and then examined using independent t-tests to evaluate whether concussion history or reading direction influence KDT performance. Following independent t-tests, the Shapiro-Wilk test and Mann-Whitney U test were run due to possible abnormal distribution of data. All data were analyzed using SPSS Statistics Version 28, and the level of significance was set to  $\alpha = 0.05$ .

## RESULTS

A total of 71 individuals were examined for their KDT performance. 13 subjects were excluded from the final analysis due to the exclusion criteria previously listed. As a result, the final analysis consisted of data from 58 eligible subjects. Demographic characteristics of these 58 subjects are described in Table 1. Findings from the chi-squares and independent t-tests indicated that none of the demographic information was significantly different between the two groups.

Independent t-tests showed that, in both the NoHx and HxC groups, respectively there was no significant difference in performance between the traditional and reverse versions of the KDT [ $t(31)=1.439$ ,  $p=0.160$ ];  $t(23)=-0.685$ ,  $p=0.500$ ]. Furthermore, it appears that subjects in both the NoHx and HxC groups did not perform significantly differently on the traditional KDT [ $t(34)=0.170$ ,  $p=0.866$ ]. Most notably, there was a statistically significant difference between the NoHx and HxC groups when performing the reverse KDT [ $t(20)=-2.371$ ,  $p=0.028$ ]. Shapiro-Wilk test showed that our sample does not fit a normal distribution, but rather a positively skewed distribution [ $p=<0.001$ ]. Additionally, Mann-Whitney U test demonstrated that the



reverse KDT reading direction in the NoHx group was not statistically significant compared to the HxC group [ $U=340.500$ ,  $p=0.179$ ].

## DISCUSSION

There has been extensive research on the use of the King-Devick Test for concussion assessment. Recent studies have identified numerous factors, such as age, sex, and other covariate factors, that may impact baseline KDT performance. The current study is the first, that we know of, to observe whether previous concussion history or reading direction (traditional vs reverse) influences KDT performance. Most notably, the results indicate a difference between the NoHx and HxC groups with regards to performance on the reverse-KDT.

The results indicate that individuals with a history of concussion perform significantly worse on the reverse-KDT than those without a history of concussion ( $p=0.028$ ). The traditional KDT has been previously found to have a sensitivity of 0.86 and a specificity of 0.90.<sup>4</sup> It can be inferred that the reverse-KDT may be a more sensitive concussion screening tool, especially among individuals with a diagnosed concussion. It is possible that lingering oculomotor deficits coupled with the increased cognitive load of the reverse-KDT may lead to slower times in individuals with a prior concussion. However, there is no literature to our knowledge that determines the utility of KDT in detecting concussion history.

Aside from our significant finding, our study also revealed some non-significant results. It demonstrated that, among the NoHx group, there is no significant difference in traditional KDT vs reverse-KDT performance. The same is also true for the HxC group; traditional vs reverse-KDT reading direction in the HxC group is non-significant. Performance of the traditional KDT in the NoHx group vs the HxC group is non-significant, meaning that both groups yielded similar results based on time and errors.

These data suggest that, compared to the traditional KDT, the reverse-KDT may be a more sensitive concussion diagnostic test, especially in individuals with a previous concussion

history. This is important because those with a history of concussion are four times more likely to sustain another concussion.<sup>22</sup> Concussion is also associated with life-long effects such as depression, anxiety, and neurodegenerative disorders, such as Alzheimer's disease and dementia.<sup>7,23,24</sup> Early recognition of concussion can improve patient outcomes.<sup>7</sup> Furthermore, the KDT is unique in that it yields reliable results regardless of the level of training of the person administering the test.<sup>1,25</sup> For example, the findings of a previous study indicate that both coaches and parents without medical training can successfully screen an athlete for a concussion while using the KDT.<sup>25</sup> To our knowledge, there are no other papers that explore the efficacy of the reverse-KDT in the current literature. Further investigation is needed to determine the reverse-KDT's effectiveness in diagnosing an acute concussion in a variety of patient populations.

This study encountered various limitations, with the first being sample size. To ensure a valid power level, this study would have ideally consisted of at least 100 participants equally distributed between the groups. It was difficult to recruit enough subjects during the COVID-19 pandemic, especially when most of the individuals who volunteered had never had a diagnosed concussion. This study was also unfortunately prone to human error. Although participants were given standardized instructions, it was impossible to perform every test without some degree of error; some participants would misunderstand the instructions, hesitate/pause during the test, or fail to stop the test upon reading the last number. A third limitation was the possibility of external factors, such as duration or time passed since an individual's previous concussion, that may have contributed to performance. It is also important to note that all participants were between 18-26 years old, as outlined in the inclusion criteria. Therefore, it is difficult to extrapolate the findings to other groups such as adolescent and older adult populations.

## CONCLUSION

This current study suggests that the reverse-KDT may be a useful concussion diagnostic test, particularly in individuals with a previous history of concussion. This implies that the reverse-KDT may be able to pick up previous concussions. It can be theorized that the reverse-KDT may

have greater sensitivity due to an increased cognitive load compared to the traditional KDT. An early and accurate concussion diagnosis is important to limit negative long-term outcomes of concussion. Further research is needed to determine the efficacy of the reverse-KDT compared to the traditional version.

TABLES

**Table 1:** Demographic Characteristics

Variables	Subjects (Total n=58)	
	NoHx (n=33)	HxC (n=25)
Age, mean±SD	21.36±1.90	21.16 ± 1.75
Sex, n (%)	F: 21 (63.64%) M: 12 (36.36%)	F: 14 (56%) M: 11 (44%)
Race, n (%)		
White	26 (78.79%)	21 (84%)
African-Amer	2 (6.06%)	3 (12%)
American Indian	1 (3.03%)	1 (3.03%)
Asian	1 (3.03%)	0 (0%)
Multi	3 (9.09%)	0 (0%)
Ethnicity, n (%)		
Non-Hispanic/Latino	30 (90.90%)	21 (84%)
Hispanic/Latino	3 (9.09%)	4 (16%)
IU Bloomington Student	Y: 31 (93.94%)	Y: 22 (88%)
Post-Secondary Education, mean±SD	3.06±1.87	2.68±1.49
Current Degree		
Bachelor	16 (48.48%)	17 (68%)
Master	15 (45.45%)	6 (24%)
Doctoral	2 (6.06%)	1 (4%)
Non-Degree	0 (0.00%)	1 (4%)
Language Proficiency		
English	17 (51.51%)	13 (52%)
Add Spanish	13 (39.39%)	8 (32%)
Add Italian	0 (0.00%)	1 (4%)
Add Chinese	1 (3.03%)	0 (0.00%)
Add Spanish & Italian	1 (3.03%)	0 (0.00%)
Add Spanish & German	0 (0.00%)	1 (4%)
Add Spanish & ASL	0 (0.00%)	1 (4%)
Add Spanish & Swahili	0 (0.00%)	1 (4%)
Add ASL	1 (3.03%)	0 (0.00%)
Hx of KDT	Y: 5 (15.15%)	Y: 3 (12%)
Physical Activity Within 60 Min	Y: 5 (15.15%)	Y: 4 (16%)
Stimulants in Past 12 Hours	Y: 15 (45.45%)	Y: 13 (52%)

Hours of Sleep, mean±SD	7.03±1.17	7.16±1.28
Level of Sleepiness, mean±SD (1=Extremely Alert, 9= Fighting Sleep)	3.42±1.79	3.84±1.60
# Diagnosed Concussions	0	1: 14 (56%) 2: 7 (28%) 3: 1 (4%) 4: 3 (12%)
Corrected Vision	Y: 20 (60.61%)	Y: 15 (60%)
Currently Wearing Contacts/Glasses	Y: 15 (45.45%), N: 5 (15.15%), N/A: 13 (39.39%)	Y: 12 (48%) N: 4 (16%) N/A: 9 (36%)
Hx of Visual/Ocular Injury	Y: 3 (9.09%)	Y: 1 (4%)
Hx of Visual/Ocular D/o	Y: 1 (3.03%)	Y: 1 (4%)

## FIGURES

Figure 1.

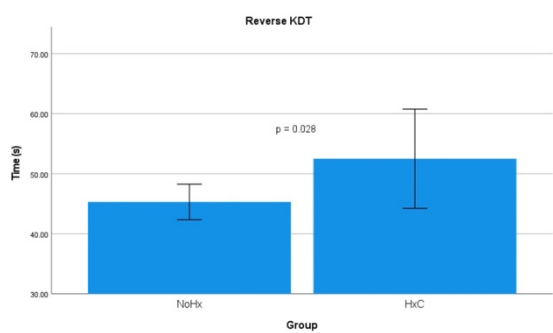


Figure 2.

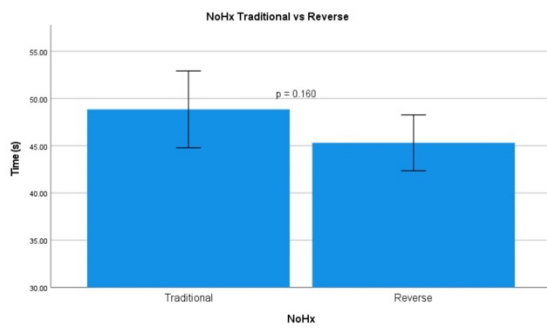


Figure 3.

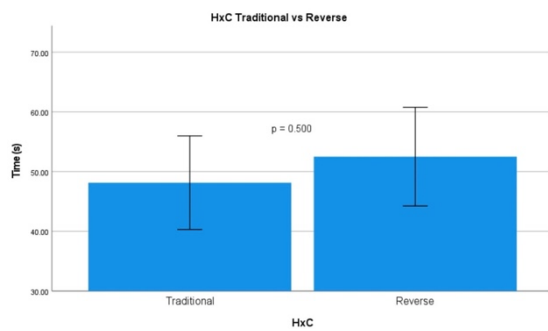
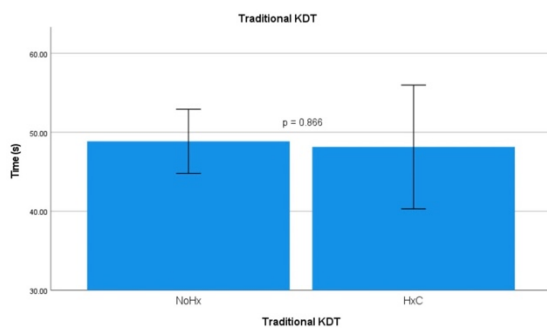


Figure 4.



## APPENDIX A

### STATEMENT OF THE PROBLEM

Based upon previous research, non-native English speakers face an additional cognitive component when performing the KDT.<sup>2,3</sup> No research has been done that investigates whether, and if so, how, the reading direction affects an individual's performance on the KDT. Therefore, the purpose of this study is to investigate if fluent English speakers, both with and without a history of concussion, perform worse while performing a reverse version of the KDT (reverse-KDT; reading the digits from right-to-left and bottom-to-top) due to the higher cognitive load of the reverse-KDT compared to the traditional reading direction.

### SPECIFIC AIMS AND HYPOTHESES

**Specific Aim 1:** To determine the effect of reading direction on KDT performance.

**Hypothesis 1a H<sub>0</sub>:** Reading direction (traditional KDT versus reverse-KDT) will not affect KDT performance, in terms of total time and number of errors.

**Hypothesis 1a H<sub>a</sub>:** Performing the KDT in reverse will result in worse performance, in terms of longer test times and greater number of errors.

**Specific Aim 2:** To examine the influence of a history of multiple concussions versus a single concussion versus no history of concussion on reverse-KDT performance.

**Hypothesis 2a H<sub>0</sub>:** There will be no differences between groups on reverse-KDT performance.

**Hypothesis 2a H<sub>a</sub>:** There will be a group effect with the history of concussion group performing worse (longest test durations and most errors) than the history of no concussion group (shortest test durations and fewest errors).

## OPERATIONAL DEFINITIONS

- Mild Traumatic Brain Injury (mTBI) – A disruption in normal brain function, which is caused by a direct or indirect blow to the head, resulting in primarily functional deficits (no major structural defects)
- Sport-Related Concussion (SRC) – A subtype of mTBI that is sustained during sport or another type of physical activity
- Second impact syndrome – A catastrophic condition in which brain swelling can occur when a concussed individual receives a second blow to the head upon prematurely returning to activity
- Return-to-Play – A progressive, stepwise protocol that an athlete must follow before being cleared to fully return to competitive physical activity/sport
- Athlete – A physically active individual who participates in sport
- Saccade – A rapid eye shift made by the eyes as they move focus between different points of fixation
- Smooth Pursuit – Allows the eyes to follow a moving object; also requires a level of predictive, cognitive effort by an individual
- Convergence – When both eyes adduct at the same time to focus maintain focus on an object
- King-Devick Test (KDT) – Timed assessment where an individual reads a series of numbers from left-to-right, top-to-bottom, as quickly and as accurately as possible
- Reverse King-Devick Test (Reverse-KDT) – Timed assessment where an individual reads a series of numbers from right-to-left, bottom-to-top, as quickly and as accurately as possible
- Error – A mistake pertaining to the KDT and Reverse-KDT when a subject adds, skips, or replaces a number which is on the test card



- Fluent English speaker – An individual whose first language is English or who demonstrates both written and verbal proficiency in the English language
- Karolinska Sleepiness Scale – A questionnaire used to subjectively evaluate each participant's perceived level of sleepiness

#### ASSUMPTIONS

- The tablet version of the KDT will provide an accurate assessment of time to complete the three reading trials.
- Participants will complete the demographic and health history questionnaire and Karolinska Sleepiness Scale honestly and truthfully.
- Participants will follow directions and perform the KDT to the best of their ability.

#### LIMITATIONS

- Participants are all young adults and enrolled as students at Indiana University Bloomington; therefore, the results may not be applicable to the general population.

#### DELIMITATIONS

- Participants will be between the ages of 18-26 years old.
- Participants are fluent English speakers.
- Participants will not be proficient in any language that reads right-to-left.
- Participants have not consumed stimulants/depressants in the previous 72 hours.
- Participants have not sustained a concussion or any other visual, ocular, or brain injury within the last 12 months.
- Participants have no history of an eye movement disorder or any uncorrected visual impairment.

- Participants do not have a diagnosis of attention deficit/hyperactivity disorder, attention deficit disorder, dyslexia, dyscalculia, or a language processing disorder.
- Testing environment will be the same for all participants.

## APPENDIX B: REVIEW OF THE LITERATURE

### INTRODUCTION

An estimated 1.6-3.8 million sports-related concussions, which are considered mild traumatic brain injuries (mTBIs), occur in the United States each year.<sup>4,6</sup> This is likely a conservative estimate, partly due to avoidance of, as well as a lack of access to, medical care, which can then lead to athletes returning to play too early.<sup>4</sup> These athletes are then at risk for protracted recovery and may also be vulnerable to second impact syndrome, a dangerous condition that results from an athlete sustaining another blow to the head upon premature return to sport.<sup>7,11</sup> The concern regarding the potential for long-term physical, cognitive, behavioral, and emotional consequences of sports-related concussions has grown over recent years.<sup>4</sup> For example, concussions have been associated with increased risk for depression, dementia and neurodegenerative disease, epilepsy, substance abuse, and, even death.<sup>4,7-9,26</sup>

### CONCUSSION AND TRAUMATIC BRAIN INJURY

Traumatic brain injury (TBI) is typically classified as either mild, moderate, or severe on the basis of Glasgow Coma Scale (GCS).<sup>12</sup> The neurologic deficits associated with mTBIs are thought to be strictly functional while more severe TBIs involve structural damage along with functional deficits.<sup>5</sup> TBIs are a significant global health problem, with approximately 10 million TBIs serious enough to lead to hospitalization or death occurring annually.<sup>4</sup> However, the proportion of the global population living with TBI-related disability is currently unknown.<sup>4</sup> Underreporting is a primary factor in the misrepresentation of national data sets, especially in the spectrum of mTBI.<sup>4</sup>

The mTBI umbrella encompasses concussions, which can be defined as a temporary change in brain function due to neuropathological damage as a result of either a direct or indirect force to the head.<sup>5,6</sup> Common signs and symptoms may include headache, dizziness, and fatigue, as well as impairments to cognition, memory, coordination, and oculomotor function.<sup>27</sup> It is important to note that concussion is a heterogenous injury—signs and symptoms often differ

substantially between individuals.<sup>5,6</sup> This can make it difficult for healthcare professionals to quickly diagnose them right away on the sideline in the case of sports-related concussions.<sup>27</sup>

Evidence suggests that engaging in exertional activities, both physical and mental, prior to full recovery can cause prolonged symptom duration.<sup>11</sup> Athletes who return to full participation too soon following a concussion are at greater risk of protracted recovery or even a further catastrophic event.<sup>7,10</sup> Concussion is also associated with life-long effects such as depression, anxiety, and neurodegenerative disorders, such as Alzheimer's disease and dementia.<sup>7,23,24</sup> Early recognition of concussion can improve outcomes.<sup>7</sup> Therefore, there is a need for a reliable, objective rapid test for use during concussion assessments.<sup>7</sup>

#### CURRENT CONCUSSION DIAGNOSTIC TESTS

A major barrier to quick and accurate concussion diagnosis is that there is no gold standard diagnostic tool for concussion assessment.<sup>5</sup> As stated above, symptom severity and the resulting degree of postural stability, memory, and oculomotor dysfunction differ among concussion patients.<sup>11</sup> However, factors influencing heterogeneous responses are inconclusive, portending that concussion assessment should incorporate a variety of neurologic elements. In other words, no single concussion diagnostic method assesses every domain, thus multiple diagnostic tests are typically used in conjunction for concussion assessment. The most common concussion assessment tools are as follows: Standard Assessment of Concussion (SAC), Balance Error Scoring System (BESS), Sport Concussion Assessment Tool 5<sup>th</sup> Edition (SCAT5), and Vestibular Ocular Motor Screening (VOMS).

The SAC is a five- to ten-minute paper and pencil test that assesses a patient's orientation, concentration, and both immediate and delayed recall.<sup>11</sup> The test is scored out of thirty points, with each question worth one point.<sup>11</sup> Performance decrements of one or more points are consistent with cognitive impairment that follows a concussion.<sup>11</sup> However, due to interindividual variances in mental acuity, having a baseline measure is crucial to make accurate decisions based on a patient's SAC score, but this is not always possible in all settings.<sup>11</sup> While

the SAC has been found to have a sensitivity of 0.80-0.94 and a specificity of 0.76-0.91, it does not test other important elements, such as coordination and oculomotor functioning, that may be affected by a concussion.<sup>11</sup> As a result, the SAC is seldom used as a standalone assessment, and it is actually a component of the SCAT5, described below.<sup>11</sup>

The BESS test evaluates patients' balance and consists of three stances: double-leg stance, single-leg stance (standing on non-dominant foot), and a tandem stance (non-dominant foot in back).<sup>13</sup> The stances are performed on a firm surface and then an unstable surface with the patient's eyes closed. The clinician then counts the number of balance errors during each twenty-second trial. Due to the subjectivity required by the examiner while counting errors, there is a wide range of inter-examiner reliability; as such, it is recommended that the same individual administer the BESS for future testing.<sup>13</sup> It is also important to note that balance can be affected by a wide range of things besides concussion: fatigue, functional ankle instability, external ankle bracing, and age.<sup>13,14</sup> BESS scores can increase with training so, in theory, an individual can cheat on future tests.<sup>13,15</sup> Again, the primary diagnostic disadvantage of the BESS is that it has neither a neuropsychological nor an oculomotor component.<sup>13</sup>

The SCAT5 is perhaps the most widely recognized concussion screening tool used by healthcare professionals.<sup>28</sup> The SCAT5 is advantageous in that it screens for a wide variety of concussion signs and symptoms.<sup>11</sup> The SCAT5 utilizes a graded symptom checklist that is to be completed by the patient in a resting state.<sup>28</sup> Then, the practitioner takes the patient through a series of examinations that test the patient's cognitive status (SAC), balance (BESS), coordination, neurological status, and both immediate and delayed memory recall.<sup>11,28</sup> The SCAT5, when administered by a healthcare professional, has been found to effectively screen for concussions for up to three days after the incident that resulted in injury.<sup>28</sup> The main limitation of the SCAT5 is that it includes a rather cursory evaluation of several areas that may be affected by a concussion.<sup>11,28</sup> Furthermore, the SCAT5 does not evaluate a patient's oculomotor function.<sup>11,28</sup>

The VOMS tool quantifies symptom provocation after completing each assessment of five domains: smooth pursuit, horizontal and vertical saccades, convergence, vestibular-ocular reflex, and visual motion sensitivity.<sup>29</sup> The VOMS has shown strong internal consistency and is able to differentiate concussed patients from controls.<sup>16,29</sup> One study showed that VOMS correctly identifies 96% of concussions if two or more symptoms appear after any portion.<sup>16</sup> The VOMS tool provokes symptoms in approximately 33-42% of concussion patients.<sup>16</sup> The VOMS does not address an individual's cognitive abilities or balance—abnormal VOMS findings may instead suggest a need for a more in-depth vestibular and oculomotor assessment and/or a treatment referral.<sup>16,29</sup>

There are limitations to concussion diagnosis as current diagnostic methods rely heavily on subjective symptom scales in addition to balance tests. Subjective measurements are inherently unreliable on their own since they depend on athletes' honesty. Balance is easily affected by fatigue and previous lower extremity injuries.<sup>1,12</sup> It is imperative for clinicians to be able to consistently detect early signs of concussion so that the patients do not suffer further neurologic injuries.<sup>7</sup>

#### KING-DEVICK TEST

When an individual engages in reading, his/her brain facilitates the activation of ocular-motor neural network as well as central neural network. This concomitant neural activation is often referred to as neuro-ophthalmologic function or circuit.<sup>30</sup> When a normal, healthy person moves their focus between fixation points while reading, their eyes make rapid horizontal shifts called saccades.<sup>30</sup> The eyes are also capable of pursuing moving objects; this process requires attention, working memory, and smooth saccadic eye movements.<sup>12</sup> The eyes converge when they simultaneously adduct to maintain focus on both near and far objects.<sup>12</sup> Furthermore, the eyes are capable of changing the shape of their lenses to accommodate objects at varying distances.<sup>12</sup> During tracking of a predictable moving target, there is a time lag (~100ms) between afferent retinal signals from the eyes to the brain and efferent motor signals from the brain to the

eye muscles.<sup>30</sup> The brain circumvents the neural delay by using spacial and temporal predictions, thus one can track the moving object smoothly and rapidly.<sup>30</sup>

Visual processes engage approximately half of the circuits in the brain.<sup>12</sup> Not surprisingly, concussed individuals often experience some sort of visual dysfunction.<sup>12</sup> Concussion patients often have difficulty with performing saccades, pursuit, convergence, and accommodation.<sup>12</sup> Therefore, objective neuro-ophthalmological function examinations can help clinicians assess concussions and monitor patient recovery.<sup>12</sup>

The King-Devick test (KDT) is a timed assessment during which individuals read aloud a series of single-digit numbers, from left to right, as fast and as accurately as possible. The test consists of one demonstration card and then three test cards, which can either be digital or on paper.<sup>7</sup> The test is scored as the sum of the three test card reading times; errors are also noted.<sup>7</sup> The KDT requires an individual's attention, language function, and eye movements such as saccades.<sup>1</sup> All of these actions are functions of the brainstem, cerebellum, the cerebral cortex, and the subcortical regions of the brain.<sup>1</sup>

Studies indicate that concussed athletes exhibit worsening (increased time) of approximately 4.8 seconds (95% CI: 3.5-5.8 s) when compared to their baseline King-Devick test.<sup>1</sup> Non-concussed athletes tend to perform better (decreased time) when compared to their baseline King-Devick test; this indicates that there is a mild learning effect.<sup>1</sup> The above findings indicate that any worsening of KDT scores may indicate the presence of a concussion.<sup>1</sup> Furthermore, research has shown that the KDT sensitivity for detecting concussion on the sideline was 86%, while specificity was 90%.<sup>1</sup>

A recent investigation showed that among concussed collegiate athletes, KDT scores worsened in 79% of individuals.<sup>21</sup> The addition of the Standard Assessment of Concussion (SAC) captured abnormalities in 89% of concussed individuals, whereas combining the KDT, SAC, and the Balance Error Scoring System (BESS) identified 100% of concussed athletes.<sup>21</sup>

Furthermore, the KDT is unique in that it yields reliable results regardless of the level of training of the person administering the test.<sup>1,25</sup> For example, the findings of a previous study indicate that both coaches and parents without medical training can successfully screen an athlete for a concussion while using the KDT.<sup>25</sup>

## FACTORS THAT AFFECT KDT PERFORMANCE

Various studies have attempted to examine the effects of factors on baseline KDT performance. Some of these factors include gender, age, sleep deprivation, having a previous history of concussion, and whether English is an individual's primary language.<sup>3,5,20</sup> Although many factors have failed to demonstrate a strong correlation to KDT performance, these factors have shown weak to moderate correlations.

It is recommended that youth athletes undergo annual KDT baseline testing due to physiological changes that occur during adolescent years. It is thought that as youth athletes age, they undergo cognitive and ocular development, allowing them to read more proficiently.<sup>31</sup> For example, youth athletes aged eight to fourteen, KDT baseline reading times improved (time decreased) by 2.9 seconds with increasing age.<sup>19</sup> Age also had a similar effect on the number of total KDT errors.<sup>19</sup> Furthermore, when compared to males of the same age, female youth athletes tend to perform approximately 5.3 seconds faster on the KDT.<sup>19</sup> Previous history of concussion has not demonstrated any significant impact on KDT baseline testing times.<sup>19</sup> This is hypothesized to be due to ongoing brain development in youth athletes.<sup>19</sup> However, more research must be performed to further understand the effects of concussion history on baseline KDT.

A recent study that compared sleep deprivation to KDT performance showed that less sleep had a negative impact on KDT score.<sup>20</sup> Whereas control subjects in the study showed a learning effect improvement of about 3.8 seconds upon KDT retest, the sleep-deprived subjects demonstrated a worsening of 0.23 seconds.<sup>20</sup> Sleep-deprived subjects exhibited impaired oculomotor function: slower peak saccadic velocity, increased spontaneous blinking, and



decreased accuracy of smooth pursuits.<sup>20</sup> However, neither caffeine consumption, gender, nor age of the subjects were able to effectively predict the effects of sleep deprivation on KDT performance.<sup>20</sup>

Furthermore, the validity of the KDT is best assured when it is performed in the native language of the participant. One study showed that when the KDT was administered in English, the native English speakers performed significantly better ( $43.8 \pm 8.6$  seconds) when compared to people who did not grow up speaking English ( $54.4 \pm 15.1$  seconds).<sup>2</sup> As a whole, the non-native English cohort displayed prolonged intersaccadic interval durations and an increased variability in the number of task-specific saccades.<sup>2</sup> It is hypothesized that translating phrases from one's native language to English provided an additional component to executive function.<sup>2</sup> In addition, it is thought that native right-to-left readers face an additional cognitive component when performing the KDT, which is designed to be read from left-to-right.<sup>2,3</sup>

## CONCLUSION

In conclusion, concussions are common injuries that are often under-reported but may contribute to the development of serious, long-term health problems. It is imperative to promptly remove an athlete with a suspected head injury from activity so that he or she is not at risk of further, and potentially catastrophic, injury. In current practice, a combination of assessment tools is used conjunctively to make a subjective decision on the diagnosis of concussion. Although the KDT can be influenced by several outside factors, previous studies indicate that it is a reliable, objective means of assessing the degree of an individual's oculomotor impairment that is associated with concussion.

## REFERENCES

1. Galetta KM, Liu M, Leong DF, Ventura RE, Galetta SL, Balcer LJJC. The King-Devick test of rapid number naming for concussion detection: meta-analysis and systematic review of the literature. 2016;1(2)
2. Rizzo J-R, Hudson TE, Amorapanth PX, et al. The effect of linguistic background on rapid number naming: implications for native versus non-native English speakers on sideline-focused concussion assessments. 2018;32(13-14):1690-1699.
3. Dickson TJ, Waddington G, Terwiel FA, Elkington L. The King-Devick test is not sensitive to self-reported history of concussion but is affected by English language skill. *J Sci Med Sport*. Aug 2019;22 Suppl 1:S34-S38. doi:10.1016/j.jsams.2018.08.013
4. Langlois JA, Rutland-Brown W, Wald MM. The epidemiology and impact of traumatic brain injury: a brief overview. *J Head Trauma Rehabil*. Sep-Oct 2006;21(5):375-8. doi:10.1097/00001199-200609000-00001
5. McCrory P, Feddermann-Demont N, Dvorak J, et al. What is the definition of sports-related concussion: a systematic review. *Br J Sports Med*. Jun 2017;51(11):877-887. doi:10.1136/bjsports-2016-097393
6. Rizzo JR, Hudson TE, Dai W, et al. Rapid number naming in chronic concussion: eye movements in the King-Devick test. 2016;3(10):801-811.
7. Galetta KM, Brandes LE, Maki K, et al. The King-Devick test and sports-related concussion: study of a rapid visual screening tool in a collegiate cohort. *J Neurol Sci*. Oct 15 2011;309(1-2):34-9. doi:10.1016/j.jns.2011.07.039
8. Kiraly MA, Kiraly SJJT. Traumatic brain injury and delayed sequelae: a review- traumatic brain injury and mild traumatic brain injury (concussion) are precursors to later-onset brain disorders, including early-onset dementia. 2007;7

9. Förstl H, Haass C, Hemmer B, Meyer B, Halle MJDÄI. Boxing—Acute Complications and Late Sequelae: From Concussion to Dementia. 2010;107(47):835.
10. Leddy J, Baker JG, Haider MN, Hinds A, Willer B. A Physiological Approach to Prolonged Recovery From Sport-Related Concussion. *J Athl Train*. Mar 2017;52(3):299-308. doi:10.4085/1062-6050-51.11.08
11. Dessy AM, Yuk FJ, Maniya AY, et al. Review of assessment scales for diagnosing and monitoring sports-related concussion. 2017;9(12)
12. Ventura RE, Balcer LJ, Galetta SL. The neuro-ophthalmology of head trauma. *Lancet Neurol*. Oct 2014;13(10):1006-16. doi:10.1016/S1474-4422(14)70111-5
13. Bell DR, Guskiewicz KM, Clark MA, Padua DAJSh. Systematic review of the balance error scoring system. 2011;3(3):287-295.
14. Docherty CL, McLeod TCV, Shultz SJJcjosm. Postural control deficits in participants with functional ankle instability as measured by the balance error scoring system. 2006;16(3):203-208.
15. Valovich TC, Perrin DH, Gansneder BM. Repeat Administration Elicits a Practice Effect With the Balance Error Scoring System but Not With the Standardized Assessment of Concussion in High School Athletes. *J Athl Train*. Mar 2003;38(1):51-56.
16. Mucha A, Collins MW, Elbin R, et al. A brief vestibular/ocular motor screening (VOMS) assessment to evaluate concussions: preliminary findings. 2014;42(10):2479-2486.
17. Resch J, Driscoll A, McCaffrey N, et al. ImPact test-retest reliability: reliably unreliable? 2013;48(4):506-511.
18. Farnsworth JL, Dargo L, Ragan BG, Kang MJJoat. Reliability of computerized neurocognitive tests for concussion assessment: a meta-analysis. 2017;52(9):826-833.

19. Moran R, Covassin TJ. Risk factors associated with baseline King-Devick performance. 2017;383:101-104.
20. Davies EC, Henderson S, Balcer LJ, Galetta SL. Residency training: the King-Devick test and sleep deprivation: study in pre-and post-call neurology residents. 2012;78(17):e103-e106.
21. Marinides Z, Galetta KM, Andrews CN, et al. Vision testing is additive to the sideline assessment of sports-related concussion. 2015;5(1):25-34.
22. van Ierssel J, Osmond M, Hamid J, Sampson M, Zemek R. What is the risk of recurrent concussion in children and adolescents aged 5–18 years? A systematic review and meta-analysis. *British journal of sports medicine*. 2021;55(12):663-669.
23. Chrisman SP, Richardson LP. Prevalence of diagnosed depression in adolescents with history of concussion. 2014;54(5):582-586.
24. Broshek DK, De Marco AP, Freeman JR. A review of post-concussion syndrome and psychological factors associated with concussion. 2015;29(2):228-237.
25. Leong DF, Balcer LJ, Galetta SL, Liu Z, Master CL. The King-Devick test as a concussion screening tool administered by sports parents. *J Sports Med Phys Fitness*. Feb 2014;54(1):70-7.
26. Veliz P, McCabe SE, Eckner JT, Schulenberg JE. Concussion, sensation-seeking and substance use among US adolescents. 2019:1-9.
27. Evans RW, Whitlow C. Acute mild traumatic brain injury (concussion) in adults. *UpToDate Inc, Waltham, MA Last reviewed November*. 2018;
28. Echemendia RJ, Meeuwisse W, McCrory P, et al. The sport concussion assessment tool 5th edition (SCAT5): background and rationale. 2017;51(11):848-850.

29. Kontos AP, Deitrick JM, Collins MW, Mucha AJ. Review of vestibular and oculomotor screening and concussion rehabilitation. 2017;52(3):256-261.
30. Rayner K. Eye movements in reading and information processing: 20 years of research. *Psychol Bull.* Nov 1998;124(3):372-422. doi:10.1037/0033-2909.124.3.372

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