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Use of the King-Devick test as a concussion assessment tool in the pediatric emergency department: a pilot study

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USE OF THE KING-DEVICK TEST AS A CONCUSSION ASSESSMENT TOOL IN THE PEDIATRIC EMERGENCY DEPARTMENT: A PILOT STUDY

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ABSTRACT

In the United States, an annual estimate of 1.36 million traumatic brain injuries present to the emergency department (ED), of which approximately 75% are concussions. Proper and timely treatment of concussion is especially important in pediatrics as children and adolescents under the age of 19 are at a higher risk for sustaining more severe and longer-lasting consequences. However, due to the wide range of symptoms at presentation, or to the potential lack of obvious symptoms, concussion can be especially difficult to diagnose in the ED setting. Neurocognitive tests provide a valuable supplement to the clinical diagnosis of concussion by objectively identifying aberrant brain activity. However, many of these tests are often too lengthy and impractical for use in the ED setting. The Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) is a 20-minute computer test that is considered to be one of the gold-standard neurocognitive tests used to diagnose concussion and track recovery. The King-Devick test (KD) is a 1-2 minute test that uses saccadic eye movements to detect suboptimal brain impairment associated with concussion. To date, there have not been any studies that analyzed the relative usability of the KD and the ImPACT in the pediatric ED (PED).

The present prospective pilot study investigates the use of the KD as a neurocognitive tool for concussion assessment in the PED and at a post-ED visit, relative

to the ImPACT, the gold standard tool for concussion diagnosis. We hypothesize that the change in performance in the KD will correlate with the change in the ImPACT results.

To date, 20 subjects between the ages of 11-18 years old presenting to the PED within 72 hours of sustaining a head injury have completed the study. The mean age of our study population was 13.6 years. The average change in test scores between PED and follow-up were: 7.2 seconds in the KD, 0.03 points in the ImPACT reaction time, 1.8 points in verbal memory, 8.3 points in visual memory, 0.8 points in visual motor speed, and 14.9 points in post-concussion symptom scale. Analysis of the correlation of the change in the KD scores to the change in the ImPACT measures revealed that the change in the KD was significantly correlated with the change in the ImPACT reaction time ($p < 0.01$), and with the change in the ImPACT verbal memory ($p < 0.05$) in the subjects that presented with LOC, 80% of whom were male.

In conclusion, our findings report that the correlation between the results of the KD and the ImPACT is more pronounced in patients presenting with more severe head trauma, such as those leading to LOC. The usability of the KD as a reliable concussion assessment tool in the PED would require further investigation with a larger sample of participants.

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LIST OF ABBREVIATIONS

Aβ..... Amyloid-beta

AD..... Alzheimer's Disease

APP ..... Amyloid Precursor Protein

ADHD..... Attention Deficit Hyperactivity Disorder

CT ..... Computed Tomography

CTE..... Chronic Traumatic Encephalopathy

DAI ..... Diffuse Axonal Injury

ED ..... Emergency Department

fMRI..... Functional Magnetic Resonance Imaging

ImPACT..... Immediate Post-Concussion Assessment and Cognitive Testing

KD..... King-Devick Test

LD ..... Learning Disability

LOC..... Loss of Consciousness

MRI..... Magnetic Resonance Imaging

MTBI..... Mild Traumatic Brain Injury

NFL..... National Football League

PED..... Pediatric Emergency Department

PCSS ..... Post-Concussion Symptom Scale

PI..... Principal Investigator

RA..... Research Assistant

RCI..... Reliability Change Index

RXT.....Reaction Time Composite Score in the ImPACT

SCAT2 .....Sport Concussion Assessment Tool 2

TBI ..... Traumatic Brain Injury

VMS..... Visual Motor Speed Composite Score in the ImPACT

VRM .....Verbal Memory Composite Score in the ImPACT

VSM..... Visual Memory Composite Score in the ImPACT

INTRODUCTION

Concussion

Concussion is the most common type of head trauma encountered in the emergency department (ED) (Langlois et al., 2006; Mannix et al., 2013). In the United States, an annual estimate of 1.36 million traumatic brain injuries present to the ED (Faul et al., 2010), of which 75% are concussions (Preiss-Farzanegan et al., 2009). Approximately 600,000 of those cases occur in children (Langlois et al., 2006; Mannix et al., 2013). Furthermore, the rate of concussion continues to rise with an estimated 60% increase in visits to the ED between 2001-2009 (CDC, 2010). While concussion is commonly associated with sports-related injuries, it occurs more frequently from falls and motor vehicle crashes (Cassidy et al., 2004).

Concussion occurs when a physical impact to the head causes an alteration in the brain's normal function (CDC, 2014). Studies of concussion frequently involve a wide range of head injuries. Common mechanisms of injury that may lead to a concussion include sports-related head strike, physical assault, motor vehicle crash, and fall (Department of Health, 2013). Concussed patients may experience symptoms of varying severity, including loss of consciousness (LOC) or memory, headache, photosensitivity, nausea, vomiting, neck pain, confusion, and difficulty concentrating (CDC, 2010).

Most concussive symptoms are temporary and tend to resolve on their own over time if managed appropriately, namely by permitting the brain to rest until it is ready to resume normal activity. Brain rest during this recovery period is particularly critical as

subsequent head injuries prior to complete recovery can impart a cumulative effect on the already damaged brain, and potentially lead to a wide range of short-term neurological sequelae, including posttraumatic migraines, second impact syndrome, and fatality (Bowen, 2003; Cantu, 1998; Collins et al., 2002; Mihalik et al., 2005; Webbe & Barthe, 2003).

Long-Term Sequelae of Concussion

There is concern about the potential increased risk of developing Alzheimer's disease (AD) in patients who have experienced concussion. A history of traumatic brain injury (TBI) has been associated with the development of AD later in life, supported by evidence such as a single episode of TBI being associated with neurodegeneration and neuronal loss (Kotapka et al., 1992; Maxwell et al., 2010; Smith et al., 1997), as well as TBI-related increase in production and accumulation of amyloid-beta (Aβ) peptide plaques, which are a hallmark of AD (McGraw-Hill, 2001). This strong link between TBIs and AD is further supported by studies that identified the presence of Aβ plaques in 30% of TBI-associated mortalities (Roberts et al., 1991; Roberts et al., 1994), suggesting that even a single TBI can induce a rapid and spontaneous formation and accumulation of Aβ plaques (Figure 1) (Ikonomovic et al., 2004; Roberts et al., 1994). Moreover, the relative risk of developing AD may depend on the severity of the injury, with increased risk of AD development associated with more serious injuries (Guo et al., 2000; Plassman et al., 2000). One especially striking finding was that TBI-triggered Aβ plaques were observed in the brains of children post-mortem, whereas in the control

group of non-neurological deaths, Aβ plaques were found almost exclusively in the elderly. This suggests that TBI is not only a real risk factor for developing AD (Lye et al., 2000; Schofield et al., 1997), but it is also capable of potentially accelerating the onset of AD (Schofield et al., 1997).

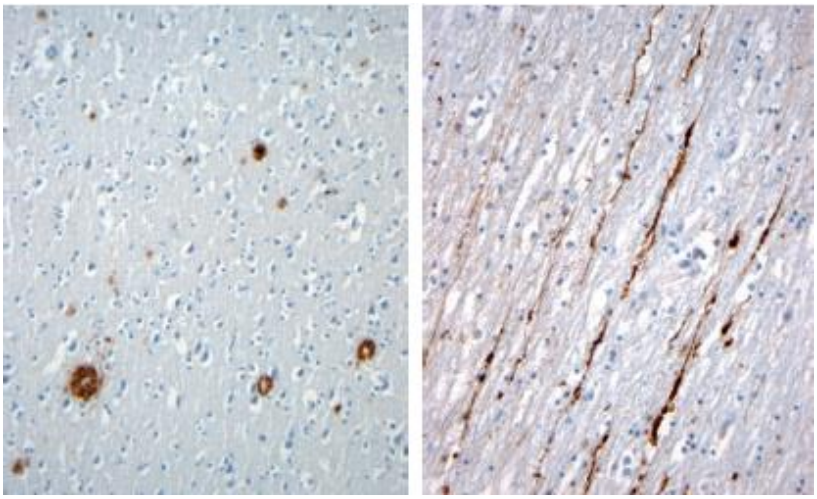

Figure 1. Immunohistochemical Staining of the Formation of Amyloid-β Plaques following Traumatic Brain Injury. Figure adapted from Johnson et al., 2010. On the left, amyloid-β (Aβ) plaques (brown) are observed in the brain of an 18 year old male 10 hours after sustaining an acute traumatic brain injury caused by a fall. On the right, accumulation of amyloid precursor protein (brown) is shown along the length of damaged axons.

Given that concussion is classified as a milder form of TBI, a TBI-related elevation in the risk of developing AD is also concerning for patients with a history of concussion. Studies have suggested that blunt head trauma can damage the brain in the

form of diffuse axonal injury (DAI), which entails "mechanical disruption and axonal swelling, disconnection and reorganization" (Tjarks et al., 2013). In addition, DAI is thought to account for the more long-term symptoms and consequences of concussion, such as impairments in the visual-motor function and lasting cognitive and emotional abnormalities (Bazarian et al., 2007; Blumbergs et al., 1994; Blumbergs et al., 1995). DAI following TBI has also been reported as the most probable sources of Aβ plaque formation (Johnson et al., 2010). DAI's disturbance of the cytoskeletal integrity can disrupt axonal transport and allow for aberrant accumulation of proteins, including amyloid precursor protein (APP), in the compromised axon (Figure 1) (Sherriff et al., 1994). APP is then cleaved into Aβ, resulting in abnormal Aβ deposits.

Another example of a long-term neurological consequence of concussion is chronic traumatic encephalopathy (CTE), most widely recognized in professional boxers and mixed martial arts fighters. CTE, previously termed "dementia pugilistica," is a neurodegenerative disorder observed in contact sports athletes as a consequence of repeat concussions (Corsellis et al., 1973; McKee et al., 2009; Millspaugh, 1937). It is characterized by an abnormal accumulation of phosphorylated tau protein deposits in the brain (Figure 2) (Baugh et al., 2012; McKee et al., 2009). Symptoms of CTE manifest progressively in forms of deteriorations in attention and memory, disorientation, confusion, headaches and dizziness, followed by diminishing insight, poor judgment, and dementia (McKee et al., 2009).

Interestingly, CTE is observed only in individuals with a history of repeat head trauma (Gavett et al., 2011; McKee et al., 2009; McKee et al., 2010; Stern et al., 2011).

The disorder was first described in boxers, whose frequent blows to the head over the course of their careers resulted in the athletes acting "punch drunk," with slurred speech, unsteady gait, and eventually more permanent neurobehavioral dysfunction, including dementia and suicide (Corsellis, 1973; Martland, 1928; Omalu et al., 2010). Amongst professional boxers who experienced repeat concussions throughout their careers, more than 17% developed CTE (McKee et al., 2009; Roberts et al., 1990; Zazryn et al., 2009). As a consequence of repeat concussion, National Football League (NFL) players are also at increased risk of developing CTE-related dementia and cognitive impairment (Guskiewicz et al., 2005). Such permanent neurobehavioral impairments associated with repeat concussions are especially concerning in pediatrics, as children with a history of head trauma have been reported to grow into more aggressive, and more socially and cognitively impaired adults compared to their peers without similar injury (Benz et al., 1999; Leon-Carrion & Ramose, 2003).

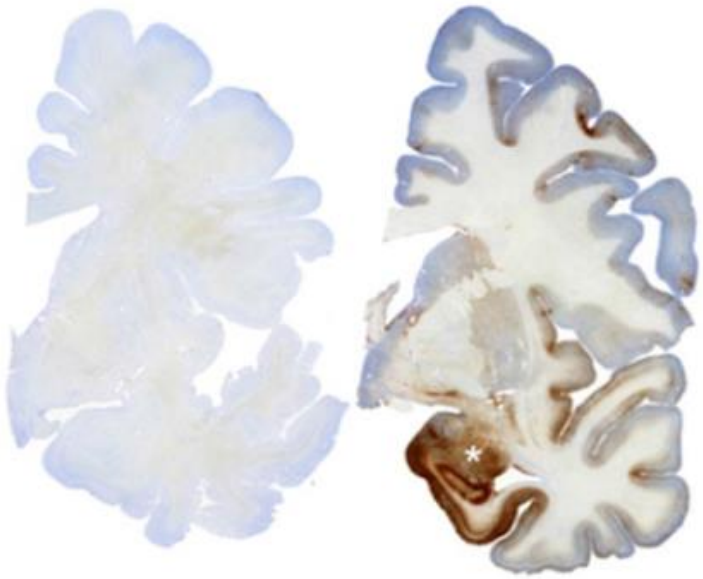

Figure 2. Gross Pathology of Chronic Traumatic Encephalopathy. Figure taken from Baugh et al., (2012). Coronal sections of the normal brain (left) and brain with CTE (right) that have been immunostained for hyperphosphorylated tau protein and tau neurofibrillary tangles. Abnormal tau deposits (brown discoloration) are noted in the CTE brain, but absent in the normal brain.

Importance of Timely Diagnosis of Pediatric Concussion

Proper and timely detection and treatment of concussion is especially important in pediatrics given that children and adolescents under the age of 19 are at a higher risk for sustaining more severe and longer-lasting consequences (Field et al., 2003; Toledo et al., 2012). The pediatric brain develops at different rates throughout growth, initially developing primary senses and motor skills by the age of 4, while the frontal areas of the brain involved in higher thinking, reasoning, judgment and impulsivity undergo critical

development during the teenage years and achieve maturation in the early 20s (Toledo et al., 2012). Thus, a patient's age and stage of brain maturation at the time of concussion may have a direct impact on prognosis (Toledo et al., 2012). Younger athletes tend to take a longer time to recover from concussion than their older peers (Field et al., 2003). In the study by Field et al., high school athletes demonstrated significant memory deficits that persisted 7 days after injury, whereas collegiate athletes had significant memory impairments only within the first 24 hours after injury (2003). The authors of this study proposed that the age-dependent responses to concussion may result from trauma-induced cerebral swelling that is more prominent and prolonged in children's underdeveloped brains than observed in adults. The immature brain's greater susceptibility to more diffuse and long-lasting cerebral swelling may further predispose children to more severe and permanent neurologic deficits if they were to sustain a second head injury during the recovery period (Cantu & Voy, 1995; Field et al., 2003; McCrory, 2001).

Concussion is the most frequently encountered form of head trauma in the pediatric emergency department (PED) (Langlois et al., 2006; Mannix et al., 2013). However, due to the wide range of symptoms at presentation, or to the lack of obvious symptoms, concussion can be especially difficult to diagnose in the ED setting (Toledo et al., 2012). To further add to the diagnostic challenge, concussion-related neurological changes cannot be detected by traditional neurodiagnostic tests, such as magnetic resonance imaging (MRI) or computed tomography (CT) (Lovell et al., 2004). Finally, underreporting of postconcussive symptoms is a common phenomenon in sports and other levels of competition (Delaney et al., 1997; Lovell et al., 2002; Lovell et al., 1998).

Fears of delayed return to play or removal from the team can prompt athletes to deny or underreport symptoms, potentially leading to premature return to play and increased risk of repeat injury.

Neurocognitive Tests for Concussion Assessment

Given the many ambiguities surrounding the symptom-based diagnosis of concussion, neurocognitive tests provide a valuable supplement by helping to identify aberrant brain activity. To date, many studies have reported that computerized neurocognitive tests, such as the Immediate Post-concussion Assessment and Cognitive Test (ImPACT), have as high as 81.9% sensitivity and 89.4% specificity in diagnosing concussion (Barr & McCrea, 2001; Collins et al., 1999; Erlanger et al., 2003; Erlanger et al., 2001; Iverson et al., 2006; Schatz et al., 2006). By assessing different areas of a patient's neurologic function through a series of memory-recall and cognitive processing speed, neurocognitive tests have shown to provide an objective evaluation of deficits that traditional symptom severity scales fail to detect (Thomas et al., 2011). However, many of the tools used to assess concussion are too costly or take too long to administer to be used widely in the ED setting. The present study aims to compare two different tools and evaluate how they may aid in the assessment of concussion in the ED.

Immediate Post-concussion Assessment and Cognitive Test (ImPACT)

The ImPACT is a 20-minute computer test that is considered to be one of the gold-standard neurocognitive tests used to diagnose concussion and track recovery (Maroon et al., 2000). As part of its comprehensive assessment of neurocognitive functions, the ImPACT incorporates into its evaluation the Post-Concussion Symptom Scale (PCSS), followed by 6 modules of neurocognitive tests that assess the participant's attention, working memory, processing speed, response variability, and nonverbal problem solving (Maerlender et al., 2010). The participant's performance in the test modules is then compiled and reported as 5 separate neurocognitive composite scores in: PCSS, Verbal Memory, Visual Memory, Visual Motor Speed, and Processing Time. The ImPACT has also been shown to have minimal practice, or learning, effect, meaning that multiple administrations of the test to the same individual is not associated with a high false negative rate (Broglio & Puetz, 2008). In fact, the clinical interpretation of the ImPACT composite scores is based on the Reliability Change Index (RCI) values (Iverson et al., 2003). The RCI values account for normal variation in the test-retest difference, as well as any practice effect that may influence test scores over repeat testing (Langlois et al., 2006; Gavett et al., 2011). Only when a subject's post-injury composite score falls short of their baseline score by a difference that exceeds the RCI is the assessment deemed abnormal and potentially warranting further assessment for concussion. It is important to note, however, that while the ImPACT reports the neurocognitive scores and automatically marks any post-injury score that differs significantly from the baseline by greater than the RCI score, the test does not classify the

overall performance as “impaired” or “recovered”, leaving it to the clinician to determine whether the patient is concussed or not concussed (Randolph, 2011). The ImPACT also generates an Impulse Control score, which determines the validity of the test score based on the participant’s performance in the testing modules. An Impulse Control score greater than 30 is used to identify athletes that are “sandbagging,” or purposely underperforming during their baseline testing in order to establish low scores that could easily be overcome when they’re retested in sideline post-injury. In this case, the ImPACT report would automatically mark the test result as invalid, prompting re-administration of the test to obtain a true baseline. The neurocognitive impairments detected by the ImPACT have been shown to correlate with altered activation of the prefrontal cortex in functional magnetic resonance imaging (fMRI), thereby further supporting the validity of the ImPACT as a reliable screening tool for concussion (Talavage et al., 2010).

The ImPACT can be administered to children as young as 11 years old (Center for Advanced Orthopedics & Sports Medicine, 2014). The test relies on establishing baseline neurocognitive data on each athlete before the season begins. Then, upon sustaining a head injury during play, the athlete may be retested and his post-injury test results compared to his own baseline in order to identify any significant underperformance on the test that warrants suspicion for concussion and immediate removal from play for further evaluation. The variability of concussive symptoms and the resulting difficulty in detecting signs of concussion have led to increased support for such neurocognitive testing tools that compare the athlete’s post-injury performance on

the test to their own baseline scores established pre-season. As these tools use individualized baseline data, they can detect even the more subtle neurological impairments that may otherwise be unnoticed or neglected by the patient, potentially predisposing them to more deleterious and permanent brain damage (Erlanger et al., 2001; Guskiewicz et al, 2001; Van Kampen et al., 2006).

The validity of the ImPACT is supported by its accuracy of assessment in the immediate aftermath of concussion and by its ability to detect any lingering neurocognitive deficits even after the clinical symptoms of concussion have resolved (Grindel et al., 2001; Iverson et al., 2002; Iverson et al., 2003; Iverson et al., 2006; Schatz et al., 2006). Though the ImPACT is typically administered prior to any head injury being sustained and then repeated within 3 days of the head injury to detect any neurocognitive defects (Schatz et al., 2006; Van Kampen et al., 2006), recent research showed that ED-assessments of concussion using the ImPACT immediately after a head injury was just as reliable as assessments performed few days after the injury (Thomas et al., 2011). The study administered the ImPACT to adolescent subjects 11-17 years of age presenting to the ED within 12 hours of sustaining a head injury and retested the participants at follow-up at least 3 days post-injury. The researchers found that ImPACT assessment in the ED reliably predicted neurocognitive deficits that were detected in a later follow-up evaluation of the concussed patients. In addition, the neurocognitive testing detected differences in the severity of concussive symptoms that clinical grading scale could not, thereby supporting the use of ImPACT as a screening tool for concussion

in the ED. However, the test's duration and resource needs (i.e., computer access) limit its usability in the ED beyond the research setting.

King-Devick Test (KD)

The KD is a test designed to examine saccadic eye movement and detect impaired oculomotor function. It involves a rapid, number-naming exercise during which the participant reads a series of single-digit numbers as fast as he can while minimizing errors. The test is scored by both a total time and by number of errors made. Notable advantages of the KD are that it can be administered by a non-medical professional and it takes only 1-2 minutes to complete, allowing for a timely assessment and referral for further evaluation if necessary. Additionally, it is composed of a portable booklet containing three test cards, allowing it to be administered in most settings.

Though originally developed as a test to identify people with dyslexia, the KD in more recent years has been studied as another potential tool to capture concussion-associated suboptimal brain function (Heitger et al., 2010) given that some degree of oculomotor dysfunction is experienced in 60-90% of patients with a head trauma (Ciuffreda et al., 2007; Lepore, 1995; Schlageter et al., 1993). The KD captures deficits in saccadic eye movements, language, and attention, all of which require the integration of the functions of the brainstem, cerebellum, and cerebral cortex (Galetta et al., 2011a; Galetta et al., 2011b). Indeed, studies have shown that concussion often results in disturbances of saccadic and other types of eye movements, evaluation of which can help predict for postconcussion syndrome (Heitger et al., 2009). In fact, in an experiment

where patients with postconcussion syndrome were compared with others who had fully recovered from head injury of similar severity, patients with postconcussion syndrome made significantly higher number of errors on antisaccade tasks ($p = 0.006$) and memory-guided sequences ($p = 0.002$) than their counterparts (Heitger et al., 2009). Thus, the KD has ongoing support as an evaluation tool in concussion studies.

The KD has increasingly been tested as a real-time tool to diagnose and track the recovery of sports-related concussions (Galetta et al., 2011a; Galetta et al., 2011b; King et al., 2012, King et al., 2013). For example, the University of Pennsylvania currently uses the KD for their athletes to assess them for possible concussion after head trauma. During the pre-season, each athlete takes the KD to establish a baseline score. When an athlete experiences head trauma, the KD can be re-administered on the sideline. Any increase in the number of errors or time taken to complete the test suggests that the athlete may have a concussion, and thus warrants immediate removal from the game and further evaluation by a clinician prior to return to play.

Study Hypothesis

To our knowledge, the utility of the KD has never been evaluated as a concussion assessment tool in the PED for patients who suffered head trauma. The present prospective pilot study will investigate the use of the KD as a neurocognitive tool for concussion assessment in the PED and at a post-ED visit, using the ImPACT as the gold standard for concussion diagnosis. We hypothesize that the change in performance in the KD will correlate with the change in the ImPACT result.

METHODS

Study Setting and Participants

The study was conducted at the Boston Medical Center PED, which is an urban, level 2 trauma center with approximately 110 visits annually for closed head injury or concussion in children 11-18 years old.

We recruited a convenience sample of children who: 1) were 11-18 years old; 2) presented to the PED within 72 hours following any kind of head injury; 3) were English-speaking; and 4) had a parent or legal guardian present to provide written consent for participation if participant was under 18 years old. We excluded those who had: 1) multisystem trauma; 2) evidence of intracranial pathology on neuroimaging; 3) intoxication with alcohol or drugs, or received opiates for analgesia in the PED; 4) a history of intellectual disability; or 5) visual deficits, including not wearing usual corrective lenses that would impair performance on the ImPACT or the KD. Patients that met the eligibility criteria were identified by the PED attending, who then notified the research assistant (RA) or the principal investigator (PI) of the study. The RA or the PI discussed the study with the patient and their guardian to determine the patient's interest in participating, and informed consent was obtained from the patient and the guardian (for patients under 18 years of age) at the time of enrollment into the study. The Boston University Medical Center Institutional Review Board reviewed and approved this study (Figure 3).

Demographic information, medical history and medication use were collected via interview to assess for any conditions that could impact test performance. Baseline data were collected on: 1) age and gender; 2) past medical history of learning disability, attention deficit hyperactivity disorder (ADHD), psychiatric illnesses, previous concussion, migraine headaches, or seizure disorder; and 3) current medications (including stimulants, opiates, antiepileptics, anticholingergics, sedatives). In addition, we collected specific data regarding the injury: 1) mechanism (sports-related, motor vehicle crash, fall, bicycle accident, assault, other); 2) time elapsed since injury; and 3) current physical symptoms.

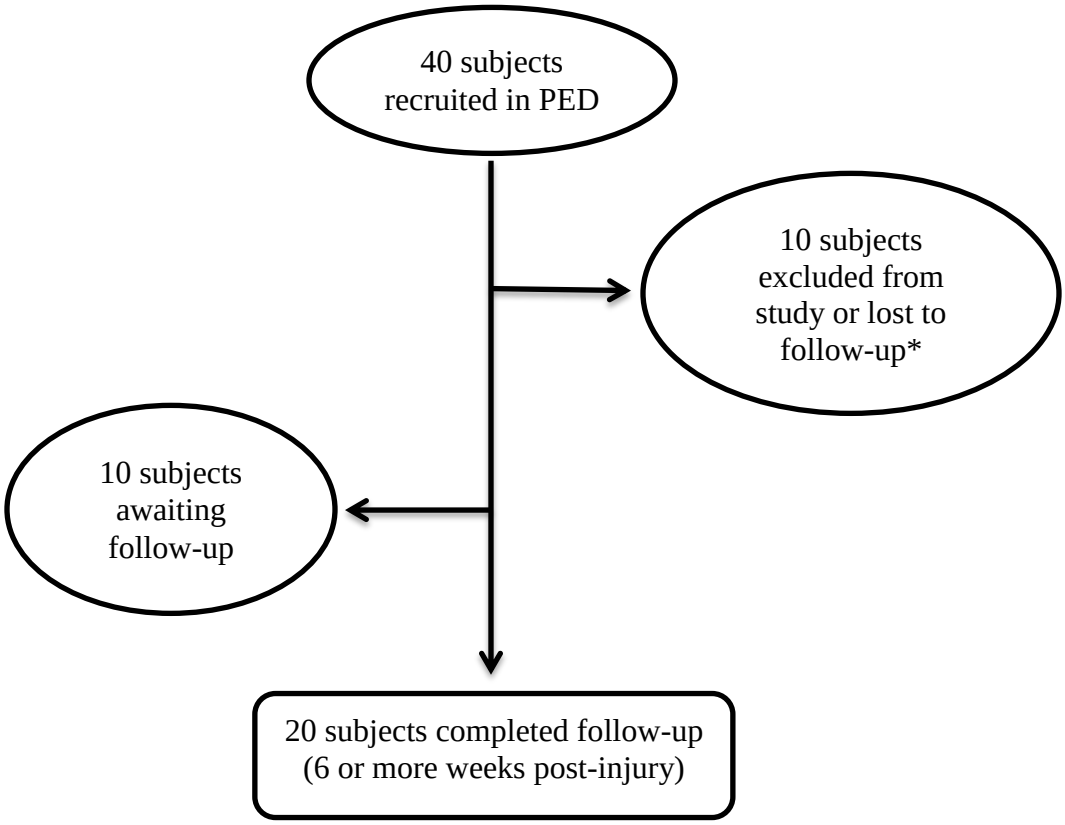

Figure 3. Subject enrollment.

*Of the 10 subjects excluded from the final results, 5 subjects declined participation in a follow-up visit and opted to terminate study enrollment. Three subjects were excluded from the study because their initial ImPACT results in the PED were marked invalid by the test's internal algorithm (impulse control score >30). One subject was excluded from the study due to parental interruptions during initial testing in the PED, resulting in unreliable test results. One subject was excluded because his lips were still anesthetized and numb from the treatment of his injury, which prevented optimal performance on the KD.

Concussion Assessments

The KD and the ImPACT were administered during the subject's PED visit. Repeat testing was performed at a follow-up appointment at least 6 weeks post-injury in order to establish test scores that may be used as the subject's "baseline" results, given that 80-90% of concussed individuals typically recover within this time span (McCrory et al., 2013). The order of test administration was randomized.

The Immediate Post-concussion Assessment and Cognitive Test (ImPACT)

A computer was provided for the subject to complete the ImPACT (Figure 4). At the start of the test, the system prompted the participant to input their demographic information, years of education, involvement in sports and medical history, including any diagnoses of learning disabilities and attention deficit hyperactivity disorder (ADHD). After completion of the demographic questionnaire, the participant proceeded to the next part of the test, the PCSS, comprised of a list of 22 concussive symptoms (Table 1). The participant documented their current symptoms based on the following grading scale: 0 indicated the absence of the symptom, 1-2=mild, 3-4=moderate, and 5-6=severe. PCSS score can range from 0 to 132. Following the PCSS evaluation, the subject completed the neurocognitive assessment portion of the test, consisting of 6 testing modules (Table 2). Results from the 6 testing modules were then compiled by the computer system to generate 4 composite scores, each named after the neurocognitive domain it reflected: verbal memory composite score (VRM), visual memory composite score (VSM), visual-motor speed composite score (VMS), and reaction time composite score (RXT). From

here on, the 5 cognitive measures of the ImPACT will refer to the PCSS and the 4 ImPACT composite scores.

The ImPACT automatically calculates the change between subjects' initial PED test scores and follow-up scores. The change in scores is considered reliably significant if the difference exceeds the RCI values (Iverson et al., 2003) established for each of the 5 aforementioned scores. As noted earlier, the ImPACT algorithm does not classify the overall performance on a test as "impaired" or "recovered," thereby leaving it to the clinician or the researcher to determine whether or not the subject is concussed (Randolph, 2011).

Several studies have reported that a significant change in one of the 5 ImPACT measures is a common phenomenon, recorded in 20 to 40% of uninjured athletes (Brogio, 2007; Maerlander et al., 2010; Randolph, 2011). Iverson et al. found that concussed athletes are likely to have significant changes in 2 or more ImPACT measures (2003). Similarly, Van Kampen et al. found that a significant increase in the PCSS score alone identified 64% of their concussed sample, and a significant change in 1 or more of the 4 ImPACT composite scores identified 83% of the sample; however, when combined, a significant change in the PCSS score and ImPACT composite scores had a 93% sensitivity in identifying concussion (2006).

Based upon the above studies, the present study identifies a subject as "concussed" at their presentation in the PED if the change in their ImPACT scores in the PED and at follow-up satisfied two criteria: 1) change in the PCSS score increased by more than the PCSS RCI; and 2) change in one or more of the 4 ImPACT composite

scores exceeded their respective RCI values. In calculating the changes in scores between testing in the PED and at follow-up, positive difference indicates an improvement in the score at follow-up compared to that from the PED for VRM, VSM, and VMS; negative difference indicates improvement for PCSS, RXT, and KD.

Table 1: Post-Concussion Symptom Scale (PCSS) of the ImPACT.

Post-Concussive Symptoms	
Headache	Nausea
Vomiting	Balance problems
Dizziness	Fatigue
Drowsiness	Trouble falling asleep
Sleeping less than usual	Sleeping more than usual
Sensitivity to light	Sensitivity to noise
Irritability	Sadness
Nervousness	Feeling more emotional
Numbness or tingling	Feeling slowed down
Feeling mentally "foggy"	Difficulty concentrating
Difficulty remembering	Visual problems (double vision, blurring, etc.)

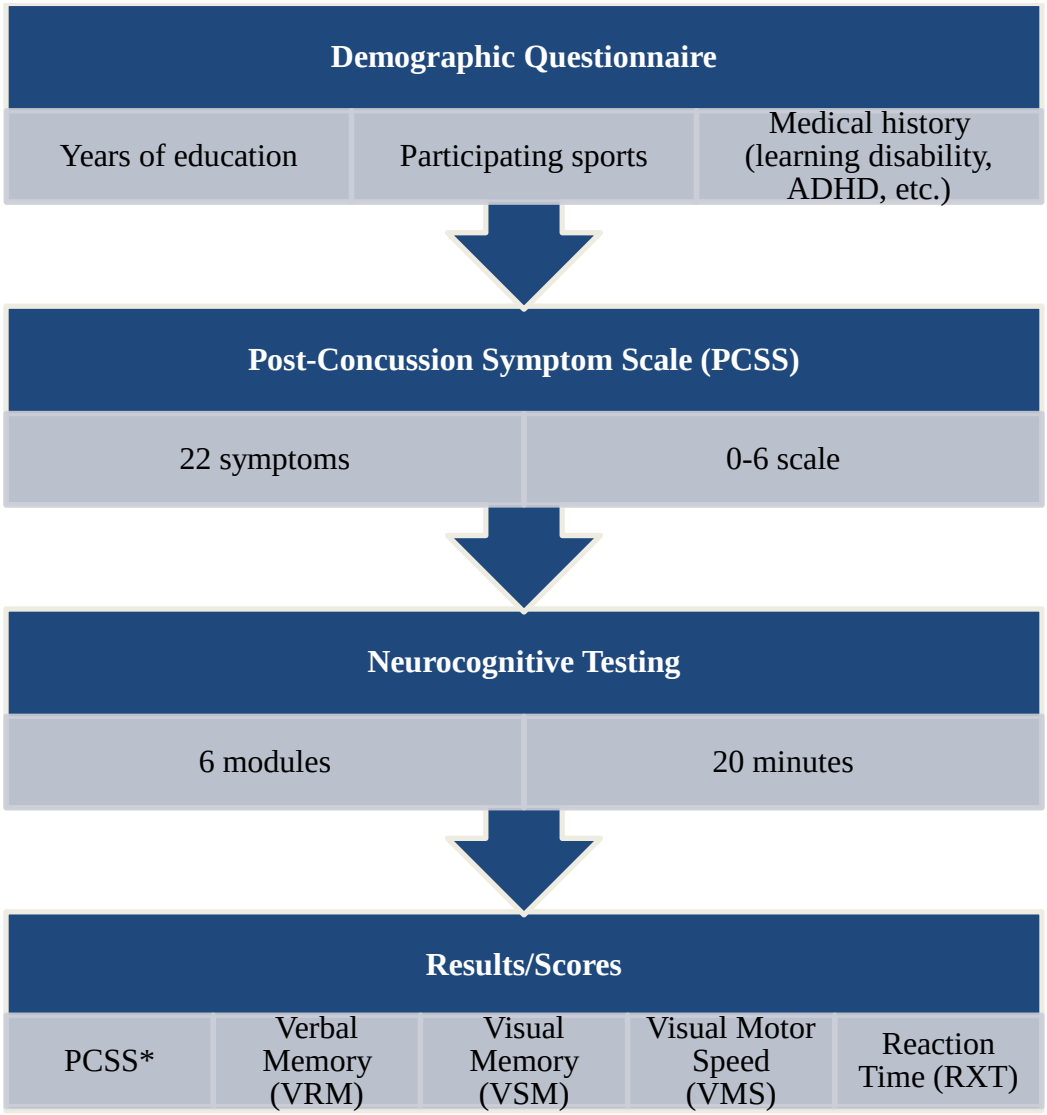

Figure 4. Components of the ImPACT. Upon completion of the test, the system generates a clinical report containing a PCSS score and 4 composite scores: VRM, VSM, VMS, and RXT.
*PCSS=Post-Concussion Symptom Scale

Table 2: ImPACT neurocognitive assessment features. Table adapted from Thomas et al., 2011. The six modules tested in the ImPACT are described, and the neurocognitive domains assessed by each module are listed.

Module	Methods	Domain(s) Evaluated
Word Discrimination	A series of 12 target words are presented and then must be identified from a series of 24 words. After other modules are completed, subject tested for recall of 12 target words.	Verbal Memory
Design Memory	A series of 12 target designs are presented and then must be identified from a series of 24 designs. After other modules are completed, subject tested for recall of 12 target designs.	Visual Memory; Verbal Memory
Xs and Os	Random assortment of Xs and Os with three of the Xs or Os illuminated in yellow. Subject must remember the location of the illuminated letters following a distracter task.	Visual Memory; Processing Speed; Reaction Time; Impulse Control
Symbol Matching	Grid presented with nine common symbols; under each symbol is a number button from 1 to 0. Symbol presented below grid; subject must quickly click the matching number.	Verbal Memory; Reaction Time
Color Match	The word "red," "blue," or "green" is displayed on the screen in the same colored ink as the word or in a different colored ink. Subject must click in the box if the word is in the matching ink.	Reaction Time; Impulse Control
Three Letters	Subject is presented with three consonant letters and must recall the three letters following a distracter task.	Verbal Memory; Visual Processing Speed

The King-Devick Test (KD)

Two administrations of the KD were administered in the PED and at the follow-up visit in order to allow the participant to familiarize himself/herself with the testing procedure and produce a score that best represents their ocular activity and neuro-ophthalmologic function. The timer was started when the subject read the first number on each of the 3 cards, and the timer was stopped when the last number on each card was read. The times recorded across the 3 cards were summed into a total, and the faster total of the two trials was reported as the subject's KD time, in addition to the number of errors made. Figure 5 shows the initial practice card and the 3 test cards that comprise the KD.

The change in the KD scores between the initial presentation to the PED and the 6+ week follow-up was used to determine whether the participant's performance improved, diminished, or stayed the same after the period of recovery. This change in score was compared with each of the changes in the 5 ImPACT cognitive measures to evaluate whether results from the KD correlated with those of the ImPACT. Studies have reported that concussed athletes, on average, performed 4 to 7 seconds (median 5 seconds or greater) slower (increase in KD time) post-injury compared to their baseline (Galetta et al., 2011b; King et al., 2012; King et al., 2013), whereas uninjured athletes, on average, performed 3 seconds faster (Galetta et al., 2011b). Accordingly, the present study considered a negative change (improvement) in the KD score by 4 or more seconds at follow-up to be a significant change from the post-injury score in the PED. We assessed

whether the subjects suggested to be concussed by the ImPACT also had improved KD score at follow-up, thus correlating with the result of the ImPACT.

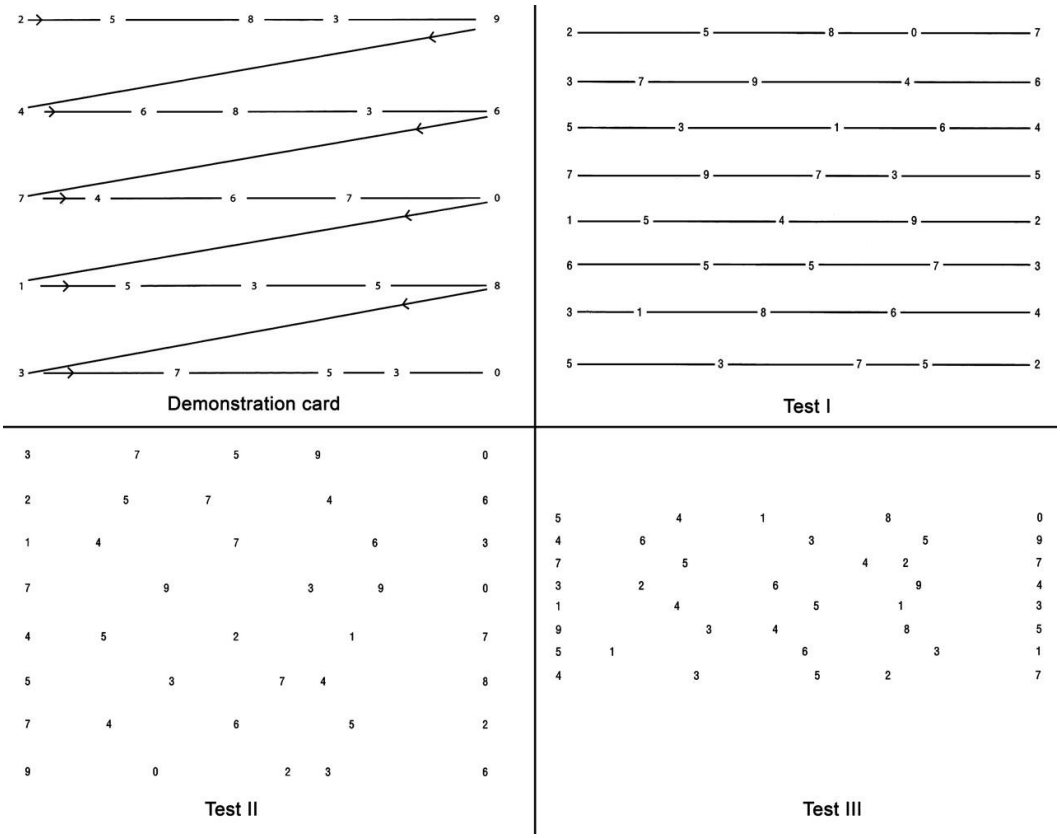

Figure 5. Demonstration and three test cards of the KD. Figure taken from Galetta et al., 2011.

Statistical Analyses

For our primary analysis, means and standard deviations of the scores obtained from each test were computed. For secondary analysis, we used the Pearson correlation to determine the association between changes in scores in the KD (in seconds) and changes in scores in each of the 5 ImPACT cognitive measures, including the PCSS, from the time of initial testing in the PED to follow-up visit 6 or more weeks later. In addition, we examined the above KD/ImPACT correlation across other collected variables, such as gender and presence of LOC.

RESULTS

In this prospective study, 40 subjects consented to participate and 20 subjects have completed the study to date. Ten subjects were lost to follow-up, 5 subjects were excluded, and 10 subjects still await follow-up (Figure 3).

For those who have completed the study, the average age was 13.7 years (SD = 1.9), 60% was male and 40% was female (Table 3). The majority of participants identified themselves as Black (70%) or Hispanic (25%), and most (85%) presented to the PED within 24 hours of sustaining the head injury. Five of the 20 (25%) participants had a diagnosis of ADHD. In addition, 5 (25%) participants had experienced LOC due to their head injury, and 4 of the 5 were male. The most common mechanisms of injury included assault, sports-related injuries, assault, and fall, each accounting for 25%, 20%, and 20% of participants, respectively (Table 4a). The most common mechanism of head injury in males was sports-related, and in females was assault (Table 4b).

Table 3: Participant demographic information of study sample (N = 20).

	***n* (%)**
Sex	
Male	12 (60)
Female	8 (40)
Average age (years)	13.7 ± 1.9
Mechanism of injury	
Sports	4 (20)
Non-sports	16 (80)
LOC*	5 (25)
Male	4 (80)
Female	1 (20)
Time elapsed from injury to PED*	
<24 hours	17 (85)
24-48 hours	3 (15)
Average time elapsed from PED to follow-up (days)	69.7 ± 45.4
Ethnicity	
Black	14 (70)
Hispanic	4 (25)
White	1 (5)
ADHD*	5 (25)

*LOC=loss of consciousness; PED=pediatric emergency department; ADHD=attention deficit hyperactivity disorder.

Mechanisms of head injury leading to LOC included: 2 unhelmeted bike injuries, 1 head-strike by a ball, 1 fall, and 1 sports-related head trauma.

Table 4a: Mechanisms of Head Injury (N=20).

Mechanism	*n* (%)
Sports	4 (20)
Non-sports	16 (80)
Motor Vehicle Crash	2 (10)
Assault	5 (25)
Fall	4 (20)
Other*	5 (25)

*Other = Two subjects sustained unhelmeted bike injuries, 1 subject hit his head on the headboard of the bed, 1 subject ran into a pole, and 1 subject was struck by a ball.

Table 4b: Mechanisms of head injury by gender (N=20).

Mechanism	Male (N=12)	Female (N=8)
Sports	4 (33.3%)	0
Motor Vehicle Crash	0	2 (25%)
Assault	3 (25%)	3 (37.5%)
Fall	1 (8.3%)	2 (25%)
Other	4 (33.3%)	1 (12.5%)

The primary outcomes of this study were changes in the test performance on the KD and the ImPACT between the initial testing during the subject's presentation to the PED and the follow-up testing 6 or more weeks post-injury. The average KD times were 53.2 ± 14.7 seconds in the PED and 46.0 ± 9.6 seconds at follow-up, resulting in an average decrease of 7.2 seconds (Table 5). For the ImPACT, the reaction time was improved by 0.03 points, verbal memory by 1.8 points, visual memory by 8.3 points, and

visual motor speed by 0.8 points. The PCSS decreased by 14.9 between the PED and follow-up visits (Table 5).

Table 5: Mean scores from the KD and the ImPACT.

Test	Average score in PED Mean (SD)	Average score at follow-up Mean (SD)	Average change in score Mean (SD)	RCI (.80) CI*
King-Devick Test, seconds	53.2 (14.7)	46.0 (9.6)	-7.2 (11.2)	
ImPACT Composite Scores				
Reaction Time	0.7 (0.2)	0.7 (0.1)	-0.03 (0.1)	0.1
Verbal Memory	80.5 (7.4)	82.3 (10.7)	+1.8 (11.6)	8.8
Visual Memory	63.0 (9.1)	71.3 (12.5)	+8.3 (13.7)	13.6
Visual Motor Speed	28.6 (7.2)	29.4 (6.8)	+0.8 (6.5)	5.0
Symptom Score (PCSS)*	24.0	9.1	-14.9	9.2

*RCI (.80) CI = Reliable Change Index value for 80% Confidence Interval
PCSS = Post-Concussion Symptom Scale

Table 6 describes individual analyses of each participant's changes in test scores between initial post-injury testing in the PED and at follow-up in 6 or more weeks, when most subjects were expected to have recovered from their injury, concussed or not concussed, and returned to baseline. Changes in ImPACT scores that exceed the RCI value are marked with an asterisk (*) to indicate a reliably significant difference. These significant differences were highlighted yellow if the changes resulted in improved scores at follow-up, and highlighted blue if the changes indicated worse test performance at

follow-up. Significant improvement in test scores at follow-up may indicate that the participant's injury at the time of initial testing was severe enough to hinder his optimal performance. Based on our criteria for defining "concussion" as a significant change in both the PCSS score and in 1 or more of the 4 ImPACT composite scores, 7 of the 20 subjects (highlighted pink) were identified as concussed. On the contrary, significant worsening in test scores using the same measurement criteria could indicate that the participant's injury hadn't fully resolved by their follow-up testing. That did not occur for any of our study subjects. One subject (ID #6) who improved significantly by 28 points in the PCSS had all 4 ImPACT measures significantly worsen at follow-up (Table 6); therefore, this subject was classified as likely not concussed. All other subjects (8 of 20) with worse results in only 1 ImPACT measure at follow-up were deemed likely not concussed, as this is consistent with the commonly observed phenomenon of healthy, unconcussed individuals performing worse in 1 ImPACT measure (but not in more than 1) (Brogio, 2007; Maerlander et al., 2010; Randolph, 2011).

The change in times in the KD was deemed significant if the difference exceeded 4 seconds, and was highlighted yellow or blue in a similar manner to the changes in ImPACT. Of the 7 subjects identified by the ImPACT as concussed at initial testing, 6 subjects (85.7%) also had significantly improved KD score at follow-up, in agreement with the ImPACT's identification of the subjects as likely concussed (Table 6). Aside from these 7 ImPACT-verified likely concussed subjects, significant change in the KD scores was noted in 7 other individuals. Two of these 7 participants performed worse (positive change in the KD score) at follow-up, suggesting longer time taken to read the

cards than at initial testing post-injury (Table 6). This could be due to poor effort or factors other than unresolved neurocognitive impairments given that neither of those participants had significant improvements or declines in their ImPACT measures (Table 6).

Table 6: Change in scores (seconds) in the ImPACT and the KD.

Subject ID	ImPACT					KD
	PCSS (RCI=9.18)	ΔVRM (RCI=8.75)	ΔVSM (RCI=13.55)	ΔVMS (RCI=4.98)	ΔRXT (RCI=0.06)	ΔKD
1	-5	-2	-7	9.14	0.03	-1
2	-3	-14*	14*	4.5	-0.09*	-4.68
3	-17*	18*	32*	11.77*	-0.39*	-37.83
4	-30*	-7	10	5.87*	0.09*	-2.03
5	-6	10*	8	-9.32*	0.03	-1.79
6	-28*	-18*	-20*	-13*	0.12*	-1.06
7	1	7	6	1.58	0.06	-34.92
8	-11*	-8	3	0.89	-0.03	4.11
9	-7	-3	13	-7.04*	-0.04	-0.32
10	0	17*	23*	2.8	0.13*	-9.76
11	3	-2	-1	-3.4	-0.01	7.51
12	-66*	5	31*	5.15*	-0.38*	-7.89
13	-5	-9*	11	-0.63	0.07*	-10.09
14	-21*	-4	-10	-5.16*	-0.08*	-6.67
15	-23*	-2	-14*	-1	-0.02	-13.58
16	-7	16*	7	-0.31	0.04	-1.05
17	-31*	28*	17*	11.69*	-0.04	-11.07
18	-20*	-2	15*	2.17	0.05	-4.2
19	-15*	5	16*	1.52	-0.04	-4.02
20	-7	1	12	-2.15	-0.07*	-2.87

For VRM, VSM, and VMS, positive difference indicates an improvement in the score at follow-up compared to that from the PED. For PCSS, RXT, and KD, negative difference indicates improvement.

*Change in score is significant, as it is greater than the RCI value

RCI=Reliability Change Index

ΔPCSS=Change in post-concussion symptom scale

ΔVRM=Change in verbal memory composite score

ΔVSM=Change in visual memory composite score

ΔVMS=Change in visual motor speed composite score

ΔRXT=Change in reaction time composite score

ΔKD=Change in the King-Devick test (KD) result in seconds

*Of the significant changes:

Improved result at follow-up if the difference in the scores exceeds the RCI in the ImPACT or 4 seconds in the KD

Worse result at follow-up if the difference in the scores exceeds the RCI in the ImPACT, or exceeds 4 seconds in the KD

Identified as "concussed" based on ImPACT

The secondary outcome of this study analyzed the Pearson correlation of the changes in KD scores compared to the changes in the ImPACT between initial and follow-up testing. Table 7 describes the correlation between the change in KD scores and the change in scores of each ImPACT measure, including the PCSS. For our sample of 20 participants who completed the study, a significant correlation was noted between the change in the KD score and the ImPACT RXT (p=0.0057). Interestingly, when stratified by gender, the correlation was significant only in the males (p=0.0176); this may be attributable to the smaller sample size of the female participants (N=8). When stratified for LOC, the only significant correlation noted was between the KD and the VRM of the ImPACT in the group with positive LOC (N=5) (p=0.0105). Notably, 4 of the 5 (80%) subjects with LOC were male (Table 3). In the group with negative LOC (N=15), weak, non-significant correlations were noted between the change in the KD score and each of the 5 ImPACT measures.

Table 7: Pearson correlation of KD score vs. ImPACT scores.

		ΔKD	
		Correlation	**p-value**
N=20	**ΔImPACT/ PCSS**	0.03328	0.8908
	VRM	0.41698	0.0671
	VSM	0.34006	0.1442
	VMS	0.32053	0.1707
	RXT	-0.58523	0.0057*
Male N=12	**ΔImPACT/ PCSS**	-0.14934	0.6517
	VRM	0.30470	0.3451
	VSM	0.38194	0.2274
	VMS	0.47014	0.1258
	RXT	0.65900	0.0176*
Female N=8	**ΔImPACT/ PCSS**	0.59954	0.1215
	VRM	0.16198	0.7148
	VSM	-0.50445	0.2144
	VMS	0.07902	0.8595
	RXT	0.20676	0.6390
Positive LOC N=5	**ΔImPACT/ PCSS**	-0.14903	0.8318
	VRM	0.94772	0.0105*
	VSM	0.71734	0.2020
	VMS	0.86071	0.0668
	RXT	-0.85459	0.0718
Negative LOC N=15	**ΔImPACT/ PCSS**	-0.00897	0.9752
	VRM	0.28289	0.3137
	VSM	0.14329	0.6172
	VMS	0.16604	0.5616
	RXT	-0.27120	0.3353

*significant correlation with p-value < 0.05

ΔKD=change in time (seconds) in the King-Devick test (KD)

ΔImPACT=change in scores in the Immediate Post-Concussion Assessment and Cognitive Test

PCSS=Post-Concussion Symptom Scale

VRM=Verbal Memory in the ImPACT

VSM=Visual Memory in the ImPACT

VMS=Visual Motor Speed in the ImPACT

RXT=Reaction Time in the ImPACT

LOC=Loss of Consciousness

DISCUSSION

The present study investigated the KD as a concussion assessment tool in the PED and compared its results to those of the ImPACT, a widely validated concussion screening tool. To our knowledge, this study is the first to compare the two tests in an ED setting caring for an urban pediatric population.

Our analysis of the correlation between change in the KD scores and change in ImPACT measures revealed that the change in the KD was significantly correlated with the change in the ImPACT RXT. When stratified for gender, this significance was noted only in males. However, 4 of the 5 LOC reported in our data were in males, thus the greater severity of head injury may have contributed to the greater significance of KD/ImPACT correlation in males. The change in the KD result was also significantly correlated with the change in the ImPACT VRM in the group that presented with LOC. These outcomes suggest that the results of the KD correlate with the results of the ImPACT, with a more pronounced correlation in subjects presenting with a higher severity of head injury/LOC.

The KD has been evaluated predominantly in sports settings as a sideline tool for concussion assessment. To date, only one study has been published that examines the value of the KD as a neurocognitive tool in the ED (Silverberg et al., 2014). The researchers of this study compared the screening ability of the KD to that of the more validated neurocognitive test, the Sport Concussion Assessment Tool 2 (SCAT2) in detecting mild traumatic brain injury (MTBI) in patients presenting to the ED. The study found that the KD reported a high false positive rate as longer times on the KD did not

correlate with poor SCAT2 performance, or with other hallmarks of MTBI such as LOC (Silverberg et al., 2014). In concluding that the study's data did not support the use of the KD as a neurocognitive tool, the authors suggested that though the KD may be a reliable tool to assess for sports-related concussion on the sideline immediately following a head injury, the sensitivity of the test declines with increasing time following the injury (Silverberg et al., 2014). Given that patients encountered in the ED often present hours to days following their injury, the authors judged the KD to be an ineffective tool for use in the ED.

To our knowledge, only two studies to date have compared the KD to the ImPACT in assessing head trauma (Tjarks et al., 2013; Vernau et al., 2015). A study by Tjarks et al. took place in a sports medicine clinic, and the study sample only included patients aged 12-19 years with sports-related injuries who required four or more clinical visits for treatment, suggesting that all participants suffered severe head trauma (Tjarks et al., 2013). The KD and the ImPACT were administered at each of the 4 clinical visits throughout the recovery period, and researchers found significant correlation in the results among the KD, the PCSS, and all 4 composites scores of the ImPACT (Tjarks et al., 2013). The authors emphasized that the KD may be especially effective in objectively assessing the recovery of concussion and thus aid in the clinicians' return-to-play decisions for the athletes. However, the generalizability of this study's results is limited due to the previously noted bias in the study sample. Vernau et al.'s study population also comprised of youth athletes aged 6-18 years whose baseline test scores showed that worse (longer) KD times were associated with worse (lower) scores in

ImPACT VMS and RXT, supporting that the result of the KD mirrors that of the ImPACT (2015). Interestingly, when clinically diagnosed concussed athletes were retested post-injury, improved test performance was noted in both the KD and the ImPACT compared to the athletes' baseline (2015). The post-injury testing was done on average 8 to 10 days after the injury and 109 days, on average, from the baseline testing. The authors suggested that such improved post-injury test results may be due to a learning effect or to continued gains over the elapsed time in developing better neurocognitive skills (Vernau et al., 2015).

The present study is unique in that it is the first to compare the KD to the ImPACT in the ED setting. Despite including subjects who presented at any time within the first 72 hours following head injury, we still found a significant correlation between the results of the KD and the ImPACT RXT and VRM (Table 7). This suggests that the KD may indeed be effective over longer time periods to identify those likely concussed, which would increase its versatility beyond a sideline tool used immediately following injury. Similar to the study by Tjarks et al., that correlation was more pronounced in subjects whose injuries were more severe or involved the presence of LOC (2013). Thus, the findings of the present study support the utility of the KD as a supplemental tool for assessing acute concussion in the PED.

Untimely detection and treatment of concussion can have harmful and long-term consequences (Bazarian et al., 2007; Blumbergs et al., 1994; Blumbergs et al., 1995; Toledo et al., 2012). The aftermath of concussion and brain injuries can be especially debilitating in children and adolescents, as it could affect school performance, requiring

special accommodations (Collins et al., 2002; Iverson et al., 2004). In addition, given that the pediatric brain undergoes critical change and reorganization during development in childhood, concussion-related neurological disturbance during this period may negatively impact the child's social and intellectual development and have lasting consequences into adulthood (Toledo et al., 2012). Furthermore, concussion continues to be a growing public health concern due to its association with increased risk for developing CTE and Alzheimer's disease. Indeed, there is growing scientific evidence in support of more active and global education of the public about concussion awareness and management.

Despite this growing body of evidence and the widely publicized deleterious and lethal consequences of repeat concussion (Benz et al., 1999; Leon-Carrion & Ramose, 2003), student athletes continue to under-report concussive symptoms for fear of losing game time or their position on the team (Lovell et al., 2002; Lovell et al., 1998). A recent study by Bramley et al. reported that 72% of athletes who received a simple educational intervention about concussion stated that they would always notify their coaches of concussive symptoms, whereas only 36% of athletes that hadn't received the training said they would honestly report their symptoms (2012). These data emphasize not only the importance of education, but also the great need for the improvement of our diagnostic acumen for concussion in the acute post-injury setting.

Limitations of this pilot study include its small sample size that prevented more robust subgroup analyses based on other demographic and clinical variables such as gender, mechanisms of injury, and presence of LOC. Second, the study also relied on a

convenience sample of participants whose enrollment into the study depended on the identification of their eligibility by the PED attending and availability of research staff. Third, because eligible subjects were recruited from the PED, pre-injury baseline data were not available. Instead, post-injury test results were collected in the PED, followed by the "baseline" results obtained at follow-up 6 or more weeks after the injury was sustained. Because both tests are designed to compare a subject's post-injury test result to his own baseline, lack of a pre-injury baseline score made it challenging to properly assess the change in an individual's scores and attribute it to potential concussion rather than to other confounding factors, such as distracting environment of the PED, lack of effort by the participant, etc. This difficulty was further pronounced for participants whose test scores at follow-up declined compared to their post-injury scores obtained in the PED, leaving no score to function as a potential baseline to which to compare their post-injury scores. Fourth, the study was conducted in a single urban center, and the ethnic diversity of the study sample was represented predominantly by Black (70%) and Hispanic (25%) subjects, limiting the generalizability of the study findings to a broader pediatric population. Fifth, 25% of our study sample reported a history of ADHD. Given that the KD captures any deficits in oculomotor function and attention (Galetta et al., 2011a; Galetta et al., 2011b), presence of LD or ADHD may interfere with the patient's performance in the KD or the ImPACT, preventing an accurate and reliable reflection of their neurocognitive abilities. Studies have reported that athletes with a LD and/or ADHD yielded significantly lower baseline scores in all of the ImPACT measures and were more prone to reporting greater numbers of PCSS symptoms than their peers

without LD or ADHD (Elbin et al., 2013; Zuckerman et al., 2013). Again, this limits the generalizability of our study population. Lastly, the noisy environment of the PED setting and unforeseen interruptions by staff and family during testing increased the difficulty of test administration. However, we did take measures to control the environment by placing every study subject in a closed room, posting signs on the doors, and requesting that family and staff minimize interruptions.

In conclusion, concussion is a prevalent injury caused by both sports- and non-sports-related mechanisms, and its occurrence is especially concerning in children and adolescents. This is the first pilot study investigating the utility of the KD as a concussion assessment tool in the PED. Our study showed significant correlation between the results of the KD and the RXT of the ImPACT and also with the VRM of the ImPACT in subjects who experienced more severe head injuries resulting in LOC. Thus, the KD may represent a useful addition to the armamentarium of neurocognitive tests for concussion evaluation. Further investigation of the KD in the ED with a larger number of more ethnically and racially diverse participants is warranted.

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CURRICULUM VITAE

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EDUCATION

Boston University School of Medicine, Boston, MA
M.S., Medical Sciences, expected May 2015

University of California – Irvine, Irvine, CA
Non-degree, post-baccalaureate studies, June 2013

University of Pennsylvania, Philadelphia, PA
B.A., Biology with distinction, May 2012

Cornell University, Ithaca, NY

RESEARCH EXPERIENCE

Boston University School of Medicine, Boston Medical Center, Pediatric Emergency Department, Boston, MA.
Sept 2014 – May 2015
Research Assistant

- Studied the usability of the King-Devick test as a tool for concussion assessment in the pediatric emergency department
- Recruited and completed follow-up testing of eligible patients presenting to the hospital

University of Pennsylvania Perelman School of Medicine, Department of Genetics, Philadelphia, PA. May 2010 – May 2012
Undergraduate researcher

- Led an independent research project studying methyl-CpG binding protein 2 (MECP2) in the development of GABAergic interneurons and behavioral deficits related to Rett Syndrome, an autism spectrum disorder
- Experienced in rodent handling, transcardial perfusion fixation of mice, gel electrophoresis and PCR to identify mutations, Western Blot and immunohistochemistry to analyze proteins in the brains of MECP2-overexpressing transgenic mice

Abramson Research Center, Children's Hospital of Philadelphia, Philadelphia, PA.
May 2010 – Jan 2011
Undergraduate researcher

- Studied short- and long-term sex-specific effects of adolescent social stress on stress susceptibility/resilience and stress coping mechanisms in adulthood using rat model

PROFESSIONAL CITATION

Article

Hong S, Flashner B, Chiu M, Ver Hoeve E, Luz S, Bhatnagar S. Social isolation in adolescence alters behaviors in the forced swim and sucrose preference tests in female but not in male rats. Physiology & Behavior 2012; 105: 269-275.

Abstract

Mickley ME, **Hong SS**, Diep P, Cabral H, Dorfman DH, Kuban K, Kavanagh, K. Use of the King Devick Test as a Neurocognitive Tool for Concussion in the Pediatric Emergency Department. Society of Academic Emergency Medicine. San Diego, CA, May 2015.

WORK EXPERIENCE

Bridge to Regenerative Biology, Institute of Regenerative Medicine, University of Pennsylvania, Philadelphia, PA.
Program Coordinator & Mentor, Oct 2010 – Apr 2012

- Coordinated and mentored for an educational research pipeline that collaborated with teachers, graduate and undergraduate mentors to coach high school students in designing, experimenting, and presenting science research projects in local and national science competitions
- Led recruiting and training of mentors and students, and oversaw the progress of 20+ research projects

VOLUNTEER EXPERIENCE

Boston Medical Center, Boston, MA
Volunteer, Mar 2015 – present

Sang K. Noh, MD Clinic, Internal Medicine, Fountain Valley, CA
Volunteer, Apr 2013 – Aug 2013

University City Hospitality Coalition, Univ. of Pennsylvania, Philadelphia, PA
Volunteer, Jan 2011 – May 2011

Wills Eye Institute, Philadelphia, PA
Volunteer Data Manager for Online Continuing Medical Education, Oct 2009 – Dec 2010

Providence Health Care, St. Paul's Hospital, Geriatric Unit, Vancouver, BC, Canada
Volunteer Caretaker, May 2009 – Aug 2009

LEADERSHIP & ACTIVITIES

Penn Science Across Ages, Barbara and Edward Netter Center for Community Partnerships, University of Pennsylvania, Philadelphia, PA
Co-President, Aug 2011 – May 2012
Chair of Operations, Sep 2009 – Aug 2011

- Helped implement inquiry-based science classes in K-6 grades by assisting teachers with lesson development and effective teaching

Reach-A-Peer Helpline, University of Pennsylvania, Philadelphia, PA
Volunteer Staff, Sept 2009 – May 2012

- Provided anonymous and confidential peer support, information, and referrals through telephone and written counseling services