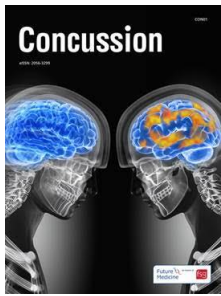


# King-Devick Test for Concussion



Concussion.2016: 1(2)

## The King-Devick test of rapid number naming for concussion detection: meta-analysis and systematic review of the literature

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**Background:** Vision encompasses a large component of the brain's pathways, yet is not represented in current sideline testing. **Objectives:** We performed a meta-analysis of published data for a vision-based test of rapid number naming (King-Devick [K-D] test). **Studies & methods:** Pooled and meta-analysis of 15 studies estimated preseason baseline K-D scores and sensitivity/specificity for identifying concussed versus nonconcussed control athletes. **Result:** Baseline K-D (n = 1419) showed a weighted estimate of 43.8 s (95% CI: 40.2, 47.5;  $I^2 = 0.0\%$ ;  $p = 0.85$  – indicating very little heterogeneity). Sensitivity was 86% (96/112 concussed athletes had K-D worsening; 95% CI: 78%, 92%); specificity was 90% (181/202 controls had no worsening; 95% CI: 85%, 93%). **Conclusion:** Rapid number naming adds to sideline assessment and contributes a critical dimension of vision to sports-related concussion testing.

### Summary Points:

- ✓ There is a concussion epidemic among athletes, and this extends to military personnel and other population groups.
- ✓ Given the widespread distribution of the visual pathways throughout the brain, a sideline test incorporating vision may aid in the diagnosis of concussion.
- ✓ The King-Devick (K-D) test, a rapid vision-based performance measure of rapid number naming, has been examined in a range of athletes at different ages and may be useful in the identification of concussion.
- ✓ Any worsening of baseline K-D test time at the time of an injury indicates a 5× greater risk of concussion.
- ✓ The K-D test was found to be reliable when administered by both trained personnel and laypersons.
- ✓ The K-D test was found to be both sensitive (86%) and specific (90%) for the detection of concussion.
- ✓ The use of K-D along with the SAC and BESS has been shown to detect 100% of clinically diagnosed concussions in this meta-analysis.
- ✓ The addition of a vision-specific concussion test to currently recommended concussion screening tools may expand the ability to detect concussion.
- ✓ Baseline K-D times have been shown to be improved (decrease) with increasing age among youth athletes.
- ✓ Baseline K-D tests should be performed at least seasonally.
- ✓ Noise has not been shown to significantly impact K-D times.
- ✓ Fatigue or competition alone does not impact K-D times; in fact, time scores often improve after vigorous exercise.
- ✓ The K-D test is a rapid, reliable, sensitive and specific test for concussion. Any worsening in time from a baseline K-D score is indicative of a concussion. The K-D test has the potential to screen for unwitnessed, or sub-concussive neurologic impairment as the result of injury from impulsive forces.



J Sci Med Sport 2018

## The King–Devick test is a valid and reliable tool for assessing sport-related concussion in Australian football: A prospective cohort study

Hecimovich M, King D, Dempsey AR, Murphy M

**Objectives:** Sport-related concussion (SRC) research has focused on impaired oculomotor function. The King–Devick (K-D) test measures oculomotor performance and is reported to identify suboptimal brain function. The use of the K-D test in Australian football (AF), a sport involving body contact and tackling, has not been documented. Therefore, the objective of this study was to determine the test-

retest reliability and diagnostic accuracy of the K-D test on a sub-elite AF team.

**Design:** Prospective cohort study.

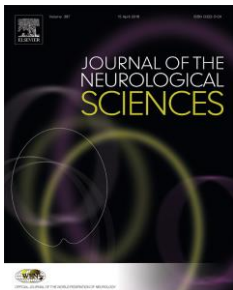
**Method:** In total, 22 male players ( $19.6 \pm 2.3$  yr) were tested and re-tested on the K-D test. Those suspected of having a SRC secondary to a significant head impact were tested. Randomly selected additional players without SRC were assessed for comparison.

**Results:** There were observable learning effects between the first and second baseline testing (48 vs. 46 s). The ICC for the first and second baseline tests was 0.91. Post-match test times were longer than the baseline times for players with SRC ( $n=7$ ) ( $-1.9$  s;  $z=-5.08$ ;  $p<0.0001$ ). Players tested with no signs of SRC ( $n=13$ ) had an improvement in time when compared with their baseline score (3.0 s;  $z=-4.38$ ;  $p<0.0001$ ). The overall sensitivity was 0.98, specificity 0.96, and a kappa of  $\kappa=0.94$ . The positive likelihood ratio was 11.6 and the positive predictive value was 89.0%.

**Conclusion:** This study supports the use of the K-D test due to its test-retest reliability, high sensitivity and specificity, and fast and simple use that is ideal for sports medicine professionals to make quick judgement on management and playability.

### Summary Points:

- ✓ There was a 2 sec improvement between the 1<sup>st</sup> and 2<sup>nd</sup> K-D Test trials, with excellent test-retest reliability for this Australian football team.
- ✓ Players with a sport-related concussion scored significantly worse than baseline. Players without concussion scored significantly faster than baseline.
- ✓ There was a high sensitivity (98%) and specificity (96%) of the K-D Test in identifying a concussed player.
- ✓ The K-D Test involves integration of functions of the brainstem, cerebellum, and cerebral cortex via visual processes and an athlete's change in score is suggestive that a meaningful neurological event has occurred.
- ✓ This study supports the use of the K-D test due to its test-retest reliability, high sensitivity and specificity, and fast and simple use that is ideal for sports medicine professionals to make quick judgement on management and playability.



J Neurol Sci 2018

## The King–Devick test in an outpatient concussion clinic: Assessing the diagnostic and prognostic value of a vision test in conjunction with exercise testing among acutely concussed adolescents

Lawrence JB, Haider MN, Leddy JJ, Hinds A, Miecznikowski JC, Willer BS

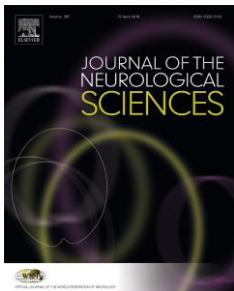
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**Objective:** This study investigated the diagnostic and prognostic value of the King–Devick (K-D) test in conjunction with treadmill testing in adolescents after sport-related concussion (SRC) in an outpatient concussion management clinic without baseline measures. **Design:** Prospective cohort. **Methods:** The K-D test was administered pre- and post-exercise on a graded treadmill test to acutely concussed (AC,  $<10$  days from injury,  $n=46$ ,  $15.4 \pm 2.1$  years) participants for 2 clinic visits (1 week apart) and to matched controls (MC,  $n=30$ ,  $15.8 \pm 1.4$  years) for 2 visits (1 week apart). Initial K-D

test times were compared between MC and AC. Changes in times from pre- to post- exercise during a treadmill test were compared for MC and AC and from Visit 1 to Visit 2. Smooth pursuits and repetitive saccades were compared with initial visit K-D test performance. **Results:** Comparison of pre-exercise K-D test times at Visit 1 distinguished MC from AC ( $46.1 \pm 9.2$  s vs.  $53.7 \pm 13.0$  s,  $p = .007$ ). Comparison of pre- and post-exercise K-D test times revealed significant improvements for MC ( $46.1 \pm 9.2$  s vs.  $43.1 \pm 8.5$  s,  $p < .001$ ) and AC who recovered by Visit 2 (Fast Recovery Group [FRG],  $n = 23$ ,  $50.4 \pm 10.0$  s vs.  $47.3 \pm 9.8$  s,  $p = .002$ ). No significant difference was seen in pre- and post-exercise K-D test times on Visit 1 for AC who took longer than 2 weeks to recover (Slow Recovery Group [SRG],  $n = 23$ ,  $57.0 \pm 15.0$  s vs.  $56.0 \pm 16.3$  s,  $p = .478$ ). At Visit 1, AC had more abnormal smooth pursuits than MC (17% vs. 3%, non-significant,  $p = .064$ ). AC, however, had significantly more abnormal repetitive saccades than MC (37% vs. 3%,  $p = .001$ ) and AC with abnormal repetitive saccades took significantly longer to complete the Visit 1 pre-exercise K-D test than AC with normal repetitive saccades ( $58.6 \pm 16.0$  s vs  $50.8 \pm 10.2$  s,  $p = .049$ ). **Conclusion:** The study supports utility of the K-D test as part of outpatient concussion assessment. Lack of improvement in K-D test performance after an exercise test may be an indicator of delayed recovery from SRC.

### Summary Points:

- ✓ Comparison of K-D test scores distinguishes healthy controls from acutely concussed adolescents in a clinical setting.
- ✓ Lack of improvement on K-D test scores after a standardized exercise protocol indicates delayed recovery from concussion.
- ✓ Acutely concussed patients with abnormal saccadic eye movements took longer on initial K-D testing compared to those patients without abnormalities.
- ✓ The K-D Test evaluates saccadic eye movements, processing speed and visual tracking.
- ✓ Cortical structures, including the frontal eye fields, supplementary eye fields, dorsolateral prefrontal cortex, parietal eye fields, and brainstem areas are involved in saccade generation.
- ✓ The incidence of oculomotor abnormalities after SRC is high and presence of these deficits is associated with prolonged recovery times. Hence the K-D test complements other sideline concussion assessment tools because of ease of use and portability. Furthermore, the test can be effectively administered by non-medically trained parents and coaches.



J Neurol Sci 2018

### **Reported concussion incidence in youth community Rugby Union and parental assessment of post head injury cognitive recovery using the King-Devick test**

Silver D, Brown N, Gissane C

**Aim:** To assess the frequency of reported head injuries in youth community Rugby Union and determine whether the King-Devick (K-D) test could be used by parents as a means to chart cognitive recovery following head injury.

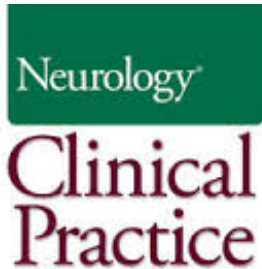
**Methods:** A prospective cohort study of 489 junior players (U9-U18) conducted at a community level Rugby Union club over four seasons. All players undertook a baseline K-D test at the start of each season. Players identified with suspected concussion performed the K-D test post injury and results were compared to their most recent baseline assessment. Parent/Guardians of the player then oversaw repeated daily testing until baseline scores were surpassed.

**Results:** 49 players were sent for assessment after suspected head injury. 46 parents oversaw daily repeated K-D testing (93.8% engagement). The median reduction in K-D test performance speed post-injury from baseline was 7.32 s (IQR 2.46 – 7.98). A median of 5.1 days/tests were taken for players to surpass baseline performance. No correlation was found between initial post-injury test and cognitive recovery time. 38 head injuries were reported from match play with an incidence rate of 12.7 per 1000 match hours (95% CI 9.2 – 17.5).

**Conclusion:** The K-D test is a practical tool for baseline, post injury and parentally supervised repeated testing within youth community Rugby Union. Incidence of reported head injuries following match play is higher than previously reported. Parental engagement was high. Post-Injury K-D test performance should not be used as a means to predict symptom recovery.

## Summary Points:

- ✓ The mean reduction in the post-injury K-D Test score in this youth rugby population was 7.32 seconds.
- ✓ K-D Test was administered reliably by parents.
- ✓ K-D Test scores returned to baseline after an average of 5.1 days (1-14 day range) following head injury.
- ✓ The K-D Test may aid in measuring aspects of cognitive recovery following a concussion.



Neurol Clin Pract 2017; 0:1-10.

### King-Devick Test Identifies Symptomatic Concussion in Real-time and Asymptomatic Concussion Over Time.

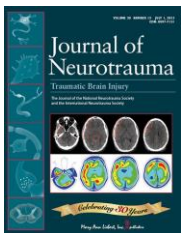
Priya Dhawan<sup>1</sup>, Amaal Starling<sup>1</sup>, Lisa Tapsell<sup>1</sup>, Jennifer S. Adler<sup>1</sup>, Steven Galetta<sup>2</sup>, Laura Balcer<sup>2</sup>, David Dodick<sup>1</sup>

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**Background:** Sports concussion has an annual incidence of approximately 3.8 million. Over half go unreported and a substantial number may be asymptomatic. A rapid, cost-effective, and reliable tool that facilitates diagnosis of concussion is needed. The King-Devick (K-D) test is a vision based tool of rapid number naming for assessment of concussion. In this study, we evaluated the utility of the K-D test in real time for identification of symptomatic concussion in youth athletes and to determine if similar impairment (subclinical concussion) exists in youth athletes without an obvious head injury or symptoms. **Methods:** Youth hockey players underwent K-D testing preseason, postseason, and immediately after suspected concussion. Additional testing was performed in a subgroup of nonconcussed athletes immediately before and after a game to determine effects of fatigue on K-D scores. **Results:** Among 141 players tested, 20 had clinically diagnosed concussion. All 20 had immediate postconcussion K-D times >5 seconds from baseline (average 7.3 seconds) and all but 2 had worse postseason scores (46.4 seconds vs 52.4 seconds,  $p < 0.05$ , Wilcoxon signed rank test). Nonconcussed athletes saw minimal improvement postseason (43.9 seconds vs 42.1 seconds,  $p < 0.05$ ) and 51 nonconcussed players assessed before and after a game revealed no significant time change as a result of fatigue. **Conclusions:** Rapid number naming using the K-D test accurately identifies realtime, symptomatic concussion in youth athletes. Scores in concussed players may remain abnormal over time. Athletes should undergo preseason and postseason K-D testing, with additional evaluation real time to inform the assessment of suspected concussion.

## Summary Points:

- ✓ Examined the K-D Test as a concussion screening tool in adolescents.
- ✓ Tested high school hockey team in pre- and post-season K-D scores and immediately following a suspected concussion.
- ✓ 20 out of 141 players sustained head injuries and had immediate post-concussion K-D scores > 5 s from baseline.
- ✓ The King-Devick Test accurately identified all diagnosed concussions immediately following the injury in these young athletes.



J Neurotrauma. 2018 Feb 8. doi: 10.1089/neu.2017.5490.

### Sideline Concussion Assessment: The King-Devick Test in Canadian Professional Football

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**Reasons for Study:** Sideline assessment tools are an important component of concussion evaluations. To date there has been little data evaluating the clinical utility of these tests in professional football. The purpose of this study was to evaluate the clinical utility of the King-Devick Test (KD) in evaluating concussions in professional football players. Baseline data was collected over 2 consecutive seasons in the Canadian Football League as part of a comprehensive medical baseline evaluation. A pilot study with the KD began in 2015 with 306 participants and the next year (2016) there were 917 participants. In addition, a sample of 64 participants completed testing after physical exertion (practice or game). **Main Findings:** Participants with concussion demonstrated significantly higher (slower) results compared with baseline and the exercise group ( $F[2,211] = 5.94, p = 0.003$ ). The data revealed a specificity of 84% and sensitivity of 62% for our sample. Reliability from season to season was good ( $ICC_{2,1} = 0.88, 95\% \text{ CI: } 0.83, 0.91$ ). On average participants improved performances by a mean of 1.9 seconds (range -26.6 to 23.8) in subsequent years. High reliability was attained in the exercise group. ( $ICC_{2,1} = 0.93, 95\% \text{ CI: } 0.89, 0.96$ ).

**Conclusions:** The K-D test presents as a reliable measure although sensitivity and specificity data from our sample indicate it should be used in conjunction with other measures for diagnosing concussion. Further research is required to identify stability of results over multiple usages.

### Summary Points:

- ✓ The K-D test identified a mean change in KD scores of 5.1 seconds than baseline.
- ✓ The data showed a 62% sensitivity and 84% specificity with a positive predictive value of 84% and negative predictive value of 62%.
- ✓ Reliability analysis showed strong reliability from season to season.
- ✓ The King-Devick test provides helpful clinical data for concussion diagnosis although it is not recommended for use as a stand-alone test.



### Proceedings from the Ice Hockey Summit III: Action on Concussion

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Tabrum29; Michael B. Stuart, MD, BSc30; Jennifer Wethe, PhD31; James R. Whitehead32; Diane Wiese-Bjornstal, PhD18; and Michael J. Stuart, MD30

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The Ice Hockey Summit III provided updated scientific evidence on concussions in hockey to inform these five objectives: 1) describe sport-related concussion (SRC) epidemiology, 2) classify prevention strategies, 3) define objective, diagnostic tests, 4) identify treatment, and 5) integrate science and clinical care into prioritized action plans and policy. Our action plan evolved from 40 scientific presentations. The 155 attendees (physicians, athletic trainers, physical therapists, nurses, neuropsychologists, scientists, engineers, coaches, and officials) voted to prioritize these action items in the final Summit session. 1) Establish a national and international hockey data base for SRC at all levels, 2) eliminate body checking in Bantam youth hockey games, 3) expand a behavior modification program (Fair Play) to all youth hockey levels, 4) enforce game ejection penalties for fighting in Junior A and professional hockey leagues, 5) establish objective tests to diagnose concussion at point of care (POC), and 6) mandate baseline testing to improve concussion diagnosis for all age groups. Expedient implementation of the Summit III prioritized action items is necessary to reduce the risk, severity, and consequences of concussion in the sport of ice hockey.

### Summary Points:

- ✓ Diagnosing Concussion in Players at Rinkside: Baseline testing preseason provides comparisons for subsequent assessments, including a symptoms scale, cognitive, and balance tests (Sideline Assessment of Concussion Test [SCAT5]) and rapid number naming tests (King-Devick Test). Players are removed from the game or practice if findings are consistent with SRC: observed mechanism of injury, signs, symptoms, abnormal physical examination, cognitive, balance, or oculomotor test as compared with baseline.
- ✓ Diagnosing Concussions and Determining Severity in a Medical Setting: Portions of the neurological examination are core to SRC office evaluations. Assessing dynamic balance and vestibular function (e.g. timed tandem gait), oculomotor function (King-Devick Test, convergence insufficiency), and vestibulocular reflex (dynamic visual acuity, head impulse test) are essential elements in the office examination of a SRC.
- ✓ Food and Drug Administration approved devices assess balance now include a King-Devick balance test app.
- ✓ Importance of Objective Diagnoses of Concussion: Objective components of an SRC diagnosis (King-Devick Test, QEEG and promising fluid neurobiomarkers) are aligning in research with SRC signs and symptoms.
- ✓ Using the King-Devick Test in Concussion Diagnosis: Eye movement and vision-related tasks involve 55% of brain pathways integral to brain integrity and are vulnerable in SRC. Rink-side SRC evaluation includes oculomotor assessment that contributes valid, critical, and objective data with greater accuracy and speed than balance and cognitive tests alone. Many SRC are not witnessed and more than 50% of athletes do not report SRC symptoms. The King-Devick Test (KDT) is a fast, valid, reliable, rapid number naming test that objectively identifies post-SRC suboptimal brain function. A meta-analysis of KDT data showed 86% sensitivity and 90% specificity for SRC, with five times greater risk of SRC (relative risk = 4.92) if KDT time and accuracy worsens between baseline and SRC testing. KDT successfully distinguished between concussed versus control in youth and collegiate athletes (receiver operating characteristic: KDT 0.92; timed tandem gait 0.87; SAC 0.68). A 3-year study of rugby players demonstrated six times more unwitnessed/unreported concussions than witnessed SRC. All were identified with KDT (100% sensitivity, 94% specificity) including players with no clinical signs or symptoms. KDT is reliably administered by medical professionals as well as trained nonmedical individuals, such as coaches and parents.



Med Sci Sports Exerc. 2019 Jan 14.

## Effects of Repetitive Head Impacts on a Concussion Assessment Battery

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3 Wake Forest Baptist Health, Department of Family Medicine, Winston-Salem, NC.

4 University of Delaware Athletics, Newark, DE.

**PURPOSE:** The purpose of this study was to determine the relationship between repetitive head impacts (RHI) and clinical concussion assessments across a season among collegiate football (FB) and women's soccer (WSOC) players. **METHODS:** Fifteen male FB and 23 WSOC players participated in this study. Participants were included if they were medically cleared for unrestricted athletic participation. Participants were tested in a university athletic training room on two occasions: pre-season (PRE) and post-season (POST). The outcome measures consisted of Tandem Gait (TG), Standardized Assessment of Concussion (SAC), Balance Error Scoring System (BESS), King-Devick (KD), Clinical Reaction Time (CRT), and Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT). RHI during the season was quantified using the Head Impact Telemetry System (HITS; Simbex, NH) for FB and the Smart Impact Monitor (SIM; Triax Technologies, CT) for WSOC. Independent variables included total number of impacts, average magnitude of peak linear acceleration, cumulative linear exposure, and number of impacts  $\geq 98g$ . **RESULTS:** Results from direct-entry multiple regression analyses suggest significant associations between RHI and both Visual Memory ( $R=0.670$ ,  $F=6.487$ ,  $p=0.002$ ) and TG ( $R=0.636$ ,  $F=3.841$ ,  $p=0.029$ ) for WSOC and between RHI and KD ( $R=0.756$ ,  $F=5.579$ ,  $p=0.013$ ) for FB, whereby those with greater exposure performed worse. No other regression analyses within or across groups were significant. **CONCLUSIONS:** These data suggest that RHI do not represent clinically meaningful changes on a multifaceted and multimodal concussion assessment battery. However, there may be subtle visual/vestibular impairments as observed by the associations between RHI and Visual Memory/TG among WSOC, RHI and KD among FB.

### Summary Points:

- ✓ The overall association between head impact exposure and KD was significant for football whereby those with greater exposure performed worse.
- ✓ The only predictors that made significant, unique contributions to the estimation of KD was number of impacts  $\geq 98g$ , whereby participants with more impacts  $\geq 98g$  performed worse.
- ✓ Analysis showed that pre to post-season assessments differed across groups. Specifically, TG and KD improved more among WSOC than FB from pre- to post-season.



Archives of Sports Medicine and Physiotherapy. Feb 2019.

## Differences in baseline and post-season King-Devick times between recreational and competitive youth soccer players

Bitussi SU, Osborne C, Juengst S, Vargas B, Dolezal C, Avers S, Ha C, Elkins N, Bell K.

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**Objective:** To determine if K-D scores differed between competitive youth soccer players and recreational youth soccer players ages 8-12. **Design:** Prospective cohort study during the spring and fall soccer seasons of 2017. Participants were 8-12 years of age and were enrolled in recreational or competitive soccer. **Methods:** Participants performed the K-D test before the first practice of the soccer season and during the last two weeks of the season. The main outcome measure was the time required to complete the K-D test before and after the soccer season in participants without a positive K-D screening for concussion. **Results:** Forty participants (19 competitive and 21 recreational) completed the study. The preseason recreational players (66.04s, SD = 15.22s) vs competitive players (59.88s, SD = 13.94s) had a mean difference of 6.16s ( $Z = .96$ ,  $p = .34$ ). The post-season recreational players (60.45s, SD = 13.46) vs competitive players (50.50s, SD = 8.49) had a mean difference of 9.95s ( $Z = 2.31$ ,  $p = .02$ ). **Conclusions:** Level of play may influence performance on the K-D. Future studies of visual efficiency in youth athletes may also provide insight into differences in performance of the K-D.

### Summary Points:

- ✓ Post-season recreational players performed worse (slower) compared to competitive players (mean difference 9.95s).

- ✓ This demonstrate a potential difference in ocular efficiency in recreational versus competitive youth soccer players.
- ✓ Setting a single threshold for a positive concussion screen across all youth soccer players could result in false positive scores among recreational players and false negative scores among competitive players. Therefore, it is imperative to establish an individual baseline for comparison when screening for concussive events.



PLoS ONE. 2017; 12(8):e0183092

## Characteristics of the King-Devick test in the assessment of concussed patients in the subacute and later stages after injury

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Although the King-Devick (K-D) test has been used frequently in assessing sports related concussion early after injury, its characteristics over time after injury and in patients with prolonged persistent symptoms are unknown. The purpose of this paper was to: evaluate the ability of the K-D Test to distinguish patients seen early after concussion from those with symptoms persisting more than 3 months compared to controls, assess changes in the K-D test times over time after concussion, and determine the relationship of K-D times to the Stroop Color and Word Test scores. We performed cross-sectional comparisons of patients with recent concussive brain injury (acute group) and those with symptoms persisting more than 3 months to healthy controls on the K-D test, the Sports Concussion Assessment Tool 3 (SCAT3), and the Stroop Color and Word Test. Longitudinal comparisons of the acute group over time within the first month after injury were also made. Post-concussive syndrome (PCS) patients had significantly higher K-D times compared to controls ( $p = 0.01$ ), while the acute group did not differ from controls ( $p = 0.33$ ). K-D times at the second visit for the acute group were similar to those of controls (54.7 vs. 49.6,  $p = 0.31$ ). While SCAT3 scores improved over time in the acute group, the K-D scores did not change between the first and second visit (55.2 vs. 54.7,  $p = 0.94$ ). K-D scores correlated significantly with the Stroop scores for all three participant groups. The K-D test is likely useful very early after concussion in conjunction with baseline scores, and while scores in PCS patients remain elevated, they can be confounded by factors such as pre-morbid depression and medication use. High correlations with Stroop scores also suggest that performance on the K-D test can by proxy provide additional insight about cognitive function and predict performance on more cognitively demanding tasks.

### Summary Points:

- ✓ The K-D test has become a popular sideline screening tool for concussions in sports, since it is easy to administer and usually takes less than two minutes to complete.
- ✓ PCS patients performed significantly worse than controls and moderately worse than the acute group of patients on the K-D test.
- ✓ Results did not show positive correlation between K-D scores and symptom scores suggesting that the reporting of subjective symptoms does not predict performance on K-D Test.
- ✓ Given results in the acute group tested within 10 days of injury the findings do not support the acute mTBI screening use of the K-D Test without a baseline score.
- ✓ Results showed novel and robust finding that K-D times were significantly correlated with Stroop Color and Word Test (patients with better, faster K-D Test times had more words correct in the Stroop Color and Word Test supporting the use of the K-D Test to indirectly indicate the level of interference control and selective attention measured by the Stroop Color and Word Test. This provides convergent validity for the K-D Test as it also assesses mental abilities such as selective attention.
- ✓ The K-D Test can by-proxy provide insightful information about more complex cerebral functions associated with selective attention, such as response inhibition.
- ✓ Findings support the value of the K-D as a screening test very early after injury.



## In situ use of the King-Devick Eye Tracking test and changes seen with sport-related concussion: saccadic and blinks counts

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Australia, School of Physiotherapy

**Objectives:** Sport-related concussion (SRC) can result in impaired oculomotor function. Oculomotor performance, measured utilizing the King-Devick/Eye Tracking test (K-D/ET), is reported to be able to identify sub-optimal brain function. The objectives of the study were to determine the diagnostic accuracy of the K-D/ET in identifying SRC occurring from game participation, and to perform a comparative analysis on saccade and blink counts for each K-D card individually and total counts between baseline and post-concussion. **Methods:** Nineteen male Australian Football players were assessed on the K-D/ET test. Those suspected of having SRC secondary to a head impact were also tested. **Results:** Participants recorded a slower time on the third ( $20.2 \pm 4.6$  s) screen when compared with the first ( $p=0.0424$ ) and second ( $p=0.0150$ ) screens. The number of blinks were higher on the third ( $2.9 \pm 2.9$ ) when compared with the second ( $p=0.0057$ ) screen. There was decrease of the K-D/ET total times between pre- and post-game ( $p=0.1769$ ). Participants who sustained a head impact recorded slower mean total K-D time ( $p=0.7322$ ), fewer mean total saccades ( $p=0.0112$ ) and more mean blinks ( $p=0.8678$ ) compared with their baseline scores. The assessment of blinks was the most sensitive measure for potential SRC (0.67). The K-D/ET duration was the most specific measure for potential SRC (0.88). An increase in the number of blinks had a fair specificity of 0.69. **Conclusion:** The rapid number-naming component of the K-D test is an assessment tool which quantifies impairment to oculomotor function and has been validated as a diagnostic tool for SRC. The clinical usefulness of the eye tracking component of the K-D/ET test is that it may be an effective method to assess concussions with the eye tracking component serving as a measure of progression and return to play. However, more research is required at the adult and youth level.

### Summary Points:

- ✓ A rapid number-naming task called the King–Devick (K–D) test has been validated as a sensitive sideline performance measure for concussion detection. This test functions as a pseudoreading task, broadly capturing aspects of afferent visual function, attention, language, visual fixation, and saccadic eye movements.
- ✓ The K-D Eye Tracking System (K-D/ET) allows for real-time automated eye movement data and output using measures of fixations, saccades, blinks, and pupillary dynamics. This eye tracking technology brings objective tools to the clinical management of oculomotor dysfunctions while allowing quantifiable measurement of impairment severity and status over progression and remediation.
- ✓ Participants who sustained a head impact recorded slower mean total K-D time ( $p=0.7322$ ), fewer mean total saccades ( $p=0.0112$ ) and more mean blinks ( $p=0.8678$ ) compared with their baseline scores. The assessment of blinks was the most sensitive measure for potential SRC (0.67). The K-D/ET duration was the most specific measure for potential SRC (0.88). An increase in the number of blinks had a fair specificity of 0.69.



Annals of Biomedical Engineering. 2018.

## Impact of Factors that Affect Reading Skill Level on King–Devick Baseline Performance Time

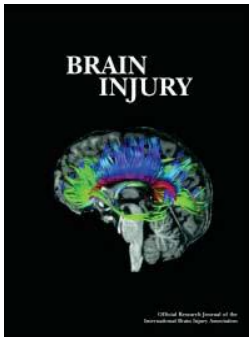
Chrisman SPD<sup>1,2</sup>, Harmon KG<sup>1</sup>, Schmidt JD<sup>3</sup>, Kaminski TW<sup>4</sup>, Buckley TA<sup>4</sup>, Kontos AP<sup>5</sup>, Clugston JR<sup>6</sup>, McCrea M<sup>7</sup>, McAllister T<sup>8</sup>, Broglio SP<sup>9</sup>, Ortega J<sup>10</sup>

1. University of Washington Seattle USA; 2. Seattle Children's Research Institute Seattle USA; 3. University of Georgia Athens USA; 4. University of Delaware Newark USA; 5. University of Pittsburgh Pittsburgh USA; 6. University of Florida Gainesville USA; 7. Medical College of Wisconsin Milwaukee USA; 8. Indiana University School of Medicine Indianapolis USA; 9. University of Michigan Ann Arbor USA; 10. Humboldt State University Arcata USA

The King–Devick (K–D) test is often used as part of a multimodal assessment to screen for sport-related concussion. However, the test involves reading numbers, and little is known about variation in baseline performance on the K–D by reading skill level. We conducted a cross-sectional study analyzing data from the Concussion Assessment, Research and Education (CARE) Consortium to assess differences in baseline performance on the K–D associated with factors that impact reading skill level (learning disorder [LD] and primary home language other than English [PHLOTE]), while controlling for covariates (gender, type of sport, attentional issues, history of concussion and modality of administration). We had a sample of 2311 student-athletes (47% female), and multivariate regression indicated an average K–D performance time of 40.4 s. Presence of LD was associated with a 3.3 s slower K–D time (95% CI 1.9–4.7,  $p < 0.001$ ), and PHLOTE was associated with a 2.6 s slower K–D time (95% CI 1.2–4.0,  $p < 0.001$ ), after controlling for other covariates. These results suggest caution in the use of normative data with the K–D. Future studies should explore the impact of factors associated with reading skill level on sensitivity of the K–D in detecting concussion.

### Summary Points:

- ✓ The King–Devick (K–D) test has been used as a rapid sideline screening test, since it evaluates complex cognitive function including visual-motor coordination, language function and attention, and thus sensitive to concussion and other brain injury.
- ✓ Multiple regions of the brain are necessary to complete the K–D test. Motor function is involved, particularly saccades (scanning from left to right across the page in a coordinated fashion) and accommodation (contracting the eye muscles in order to focus on and read the numbers). The amplitude of saccadic eye movement is associated with the oculomotor nuclei, whereas the direction of these eye movements is associated with the reticular formation. Individuals completing the K–D must also recognize single digit numbers, a function that has been localized to the inferior temporal gyrus. They must then associate each number with the English word for that number and contract the oral musculature to say the word for each number aloud, which involves both language comprehension (Wernicke's area) and language production (Broca's area).
- ✓ Multiple regression analysis including presence of LD and PHLOTE (primary home language other than English) in addition to other covariates had the best model fit, and indicated a 3.3 s longer K–D performance time for those with LD (95% CI 1.9–4.7,  $p < 0.001$ ) and 2.6 s longer K–D time (95% CI 1.2–4.0,  $p < 0.001$ ) for those with PHLOTE.
- ✓ These results suggest caution in using normative data with the K–D test, as these factors may result in false positive findings in the absence of concussion.



Brain Injury. 2018.

## The King-Devick test in mixed martial arts: the immediate consequences of knock-outs, technical knock-outs, and chokes on brain functions

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*Minnesota Combative Sports Commission, St. Paul, MN, USA*

The aim of this prospective cohort study was to determine the effect of an ‘event,’ defined as a knockout (KO), technical knock-out (TKO), choke, or submission, on King-Devick (K-D) test times in mixed martial arts (MMA) athletes. MMA athletes ( $28.3 \pm 6.6$  years,  $n = 92$ ) underwent K-D testing prior to and following a workout or match. Comparison of baseline and post-workout/match K-D times to assess any significant change. K-D tests worsened (longer) in a majority of athletes following an ‘event’ ( $N = 21$ ) ( $49.6 \pm 7.8$  s vs  $46.6 \pm 7.8$  s,  $p = 0.0156$ , Wilcoxon signed-rank test). K-D tests improved (shorter) following a standard workout or match in which no ‘event’ occurred in a majority of cases ( $n = 69$ ) ( $44.2 \pm 7.2$  s vs  $49.2 \pm 10.9$  s,  $p = <0.0001$ , Wilcoxon signed-rank test). Longer duration (worsening) of postmatch K-D tests occurred in most athletes sustaining an ‘event’; K-D tests shortened (improved) in a majority of athletes not sustaining an ‘event’. Our study suggests MMA athletes suffering an ‘event’ may have sustained a brain injury similar to a concussion.

### Summary Points:

- ✓ The sensitivity of the K-D was 87% for detecting athletes with probable brain injury (defined as a witnessed KO or TKO with a subsequent slowed K-D test).
- ✓ This study confirms that following a KD or TKO in MMA, in a majority of athletes, the K-D time is slower than baseline and, occasionally, the fighters also make errors on testing.
- ✓ This study also demonstrated slowed K-D times in a majority of athletes who sustained “events” such as chokes, near chokes, or submission holds. These findings suggest that these “events” may also impair brain function and represent a concussive event.



Journal of Neurological Sciences. 2017; 379:312-317.

## Rapid sideline performance meets outpatient clinic: Results from a multidisciplinary concussion center registry

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**Objective:** This study investigated the utility of sideline concussion tests, including components of the Sports Concussion Assessment Tool, 3rd Edition (SCAT3) and the King-Devick (K-D), a vision-based test of rapid number naming, in an outpatient, multidisciplinary concussion center treating patients with both sports-related and non-sports related concussions. The ability of these tests to predict clinical outcomes based on the scores at the initial visit was evaluated.

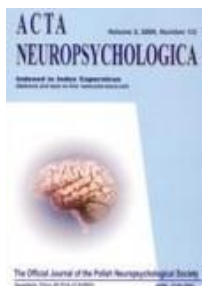
**Methods:** Scores for components of the SCAT3 and the K-D were fit into regression models accounting for age, gender, and sport/non-sport etiology in order to predict clinical outcome measures including total number of visits to the concussion center, whether the patient reached a SCAT3 symptom severity score  $\leq 7$ , and the total types of referrals each patient received over their course. Patient characteristics, differences between those with sport and non-sport etiologies, and correlations between the tests were also analyzed. **Results:** Among 426 patients with concussion, SCAT3 total symptom score and symptom severity score at the initial visit predicted each of the clinical outcome variables. K-D score

at the initial visit predicted the total number of visits and the total number of referrals. Those with sports-related concussions were younger, had less severely affected test scores, had fewer visits and types of referrals, and were more likely to have clinical resolution of their concussion and to reach a symptom severity score  $\leq 7$ .

**Conclusions:** This large-scale study of concussion patients supports the use of sideline concussion tests as part of outpatient concussion assessment, especially the total symptom and symptom severity score portions of the SCAT3 and the K-D. Women in this cohort had higher total symptom and symptom severity scores compared to men. Our data also suggest that those with non-sports-related concussions have longer lasting symptoms than those with sports-related concussions, and that these two groups should perhaps be regarded separately when assessing outcomes and needs in a multidisciplinary setting.

### Summary Points:

- ✓ The King-Devick (K-D) test score at the initial visit predicted the total number of visits and the total number of referrals.
- ✓ SCAT3 total symptom score and symptom severity score at the initial visit predicted each of the clinical outcome variables.
- ✓ This study supports the use of sideline concussion tests as part of outpatient concussion treatment, especially the total symptom and symptom severity score portions of the SCAT3 and the K-D.



Acta Neuropsychologica 2015;13(3):229-36

### **The King-Devick Test: An indicator of longer-term cognitive effects post-concussion**

Bernstein JPK, Mitchell LS, Bazarian JJ, Langfitt JT

**Background:** The King-Devick test (K-D) was introduced in 2011 as a quick, easy and cost-effective way to screen for a concussion. Relying on differences in visual scanning between a baseline and post-injury examination to discern a concussion, the test has been found to be sensitive to concussions immediately (within minutes) following injury. The aim of this paper was to determine whether the K-D is sensitive to residual effects of a concussion.

**Material/Methods:** Performance on the K-D was compared in a sample of 13 subjects tested 1-60 days after a concussion and 17 matched non-concussed controls. We also compared subjects' performances on standard neuropsychological measures of convergent validity (attention, working memory and processing speed) and discriminant validity (IQ and motor speed).

**Results:** Consistent with hypotheses, concussed subjects performed worse on the K-D than non-concussed subjects. K-D performance was correlated with tests that measured attention and processing speed, but was unrelated to estimated IQ. There was a trend for subjects with a prior history of concussion to perform worse on the K-D than subjects for whom this was their first concussion.

**Conclusions:** These results provide initial support for convergent and criterion validity of the K-D as a measure of attention and processing speed that is sensitive to persisting effects of concussion.

### Summary Points:

- ✓ Individuals with a recent history of concussion (1-60 days post-concussion) performed worse on the K-D Test than the non-concussed controls.
- ✓ K-D Test scores were correlated with other tests of attention and processing but not estimated IQ scores.
- ✓ This study demonstrated that K-D Test is sensitive to persisting effects of a concussion in the days and weeks following injury.





Journal of Neuro-ophthalmology. 2017.

## Rapid Number Naming and Quantitative Eye Movements May Reflect Contact Sport Exposure in a Collegiate Ice Hockey Cohort

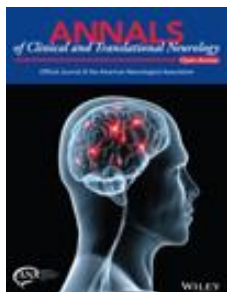
Hasanaj, Lisena MPA; Thawani, Sujata P. MD, MPH; Webb, Nikki ATC; Drattell, Julia D. MED; Serrano, Liliana MPH; Nolan, Rachel C.; Raynowska, Jenelle MD; Hudson, Todd E. PhD; Rizzo, John-Ross MD; Dai, Weiwei; McComb, Bryan BS; Goldberg, Judith D. ScD;

Rucker, Janet C. MD; Galetta, Steven L. MD; Balcer, Laura J. MD, MSCE; *Departments of Neurology, Population Health, Physical Medicine and Rehabilitation, New York University School of Medicine, New York, New York.*

**Background:** The King-Devick (K-D) test of rapid number naming is a reliable visual performance measure that is a sensitive sideline indicator of concussion when time scores worsen (lengthen) from preseason baseline. Within cohorts of youth athletes <18 years old, baseline K-D times become faster with increasing age. We determined the relation of rapid number-naming time scores on the K-D test to electronic measurements of saccade performance during preseason baseline assessments in a collegiate ice hockey team cohort. Within this group of young adult athletes, we also sought to examine the potential role for player age in determining baseline scores. **Methods:** Athletes from a collegiate ice hockey team received preseason baseline testing as part of an ongoing study of rapid rink-side performance measures for concussion. These included the K-D test (spiral-bound cards and tablet computer versions). Participants also performed a laboratory-based version of the K-D test with simultaneous infrared-based video-oculographic recordings using an EyeLink 1000+. This allowed measurement of the temporal and spatial characteristics of eye movements, including saccadic velocity, duration, and intersaccadic interval (ISI). **Results:** Among 13 male athletes, aged 18-23 years (mean 20.5 +/- 1.6 years), prolongation of the ISI (a combined measure of saccade latency and fixation duration) was the measure most associated with slower baseline time scores for the EyeLink-paired K-D (mean 38.2 +/- 6.2 seconds,  $r = 0.88$  [95% CI 0.63-0.96],  $P = 0.0001$ ), the K-D spiral-bound cards (36.6 +/- 5.9 seconds,  $r = 0.60$  [95% CI 0.08-0.87],  $P = 0.03$ ), and K-D computerized tablet version (39.1 +/- 5.4 seconds,  $r = 0.79$  [95% CI 0.42-0.93],  $P = 0.001$ ). In this cohort, older age was a predictor of longer (worse) K-D baseline time performance (age vs EyeLink-paired K-D:  $r = 0.70$  [95% CI 0.24-0.90],  $P = 0.008$ ; age vs K-D spiral-bound cards:  $r = 0.57$  [95% CI 0.03-0.85],  $P = 0.04$ ; age vs K-D tablet version:  $r = 0.59$  [95% CI 0.06-0.86],  $P = 0.03$ ) as well as prolonged ISI ( $r = 0.62$  [95% CI 0.11-0.87],  $P = 0.02$ ). Slower baseline K-D times were not associated with greater numbers of reported prior concussions. **Conclusions:** Rapid number-naming performance using the K-D at preseason baseline in this small cohort of collegiate ice hockey players is best correlated with ISI among eye movement-recording measures. Baseline K-D scores notably worsened with increasing age, but not with numbers of prior concussions in this small cohort. While these findings require further investigation by larger studies of contact and noncontact sports athletes, they suggest that duration of contact sports exposure may influence preseason test performance.

### Summary Points:

- ✓ Inter-saccadic intervals (ISI) time represents a combined measure of saccade latency and fixation duration.
- ✓ ISI in this cohort was associated with slower baseline K-D scores.
- ✓ In this cohort age was associated with slower baseline K-D scores and may suggest that duration of contact sports exposure may influence preseason performance therefore highlights the importance of establishing an individual baseline and not using normative data for comparison.



Annals of Clinical and Translational Neurology. 2016;3(10):801-811.

## Rapid number naming in chronic concussion: eye movements in the King-Devick test

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Computer Engineering, NYU Tandon School of Engineering, New York, New York; <sup>4</sup>Department of Population

**Objective:** The King–Devick (KD) test, which is based on rapid number naming speed, is a performance measure that adds vision and eye movement assessments to sideline concussion testing. We performed a laboratory-based study to characterize ocular motor behavior during the KD test in a patient cohort with chronic concussion to identify features associated with prolonged KD reading times. **Methods:** Twenty-five patients with a concussion history (mean age: 31) were compared to control participants with no concussion history (n = 42, mean age: 32). Participants performed a computerized KD test under infrared based video-oculography. **Results:** Average intersaccadic intervals for task-specific saccades were significantly longer among concussed patients compared to controls ( $324.4 \pm 85.6$  msec vs.  $286.1 \pm 49.7$  msec,  $P = 0.027$ ). Digitized KD reading times were prolonged in concussed participants versus controls ( $53.43 \pm 14.04$  sec vs.  $43.80 \pm 8.55$  sec,  $P = 0.004$ ) and were highly correlated with intersaccadic intervals. Concussion was also associated with a greater number of saccades during number reading and larger average deviations of saccade endpoint distances from the centers of the to-be-read numbers ( $1.22 \pm 0.29^\circ$  vs.  $0.98 \pm 0.27^\circ$ ,  $P = 0.002$ ). There were no differences in saccade peak velocity, duration, or amplitude. **Interpretation:** Prolonged intersaccadic intervals, greater numbers of saccades, and larger deviations of saccade endpoints underlie prolonged KD reading times in chronic concussion. The KD test relies upon a diffuse neurocognitive network that mediates the fine control of efferent visual function. One sequela of chronic concussion may be disruption of this system, which may produce deficits in spatial target selection and planning of eye movements.

### Summary Points:

- ✓ Laboratory-based eye movement study completed to determine eye movement performance in a concussion cohort to identify features leading to KD reading time prolongation in concussion.
- ✓ Inter-saccadic intervals (ISI) time represents a combined measure of saccade latency and fixation duration.
- ✓ ISI was greater in concussed subjects vs. non-concussed controls.
- ✓ Digitized KD reading times were prolonged in concussed vs. non-concussed controls.
- ✓ There were no differences in saccade velocity, acceleration or deceleration between groups.
- ✓ ISI and number of saccades (small amplitude, <20deg) correlated with K-D time.
- ✓ ISI and number of saccades (small amplitude, <20deg) also correlated with change in Post Concussion Symptom Inventory (PCSI) score.
- ✓ Efficient K-D test performance requires eye movements that are not only rapid and accurate, but also requires the integration of information obtained continuously from each fixation to read, verbalize, plan the motor movement, and direct attention to the next number.



Journal of the Neurological Sciences. 2016;370:305-309.

### **Assessment of the King-Devick (KD) test for screening acute mTBI/concussion in warfighters**

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**OBJECTIVES:** The Department of Defense reported that 344,030 cases of traumatic brain injury (TBI) were clinically confirmed from 2000 to 2015, with mild TBI (mTBI) accounting for 82.3 percent of all cases. Unfortunately, warfighters with TBI are often identified only when moderate or severe head injuries have occurred, leaving more subtle mTBI cases undiagnosed. This study aims to identify and validate an eye-movement visual test for screening acute mTBI.

**METHODS:** Two-hundred active duty military personnel were recruited to perform the King-Devick® (KD) test.

Subjects were equally divided into two groups: those with diagnosed acute mTBI ( $\leq 72$  hours) and age-matched controls. The KD test was administered twice for test-retest reliability, and the outcome measure was total cumulative time to complete each test. **RESULTS:** The mTBI group had approximately 36 percent mean slower performance time with significant differences between the groups ( $p < 0.001$ ) in both tests. There were significant differences between the two KD test administrations in each group, however, a strong correlation was observed between each test administration. **CONCLUSIONS:** Significant differences in KD test performance were seen between the acute mTBI and control groups. The results suggest the KD test can be utilized for screening acute mTBI. A validated and rapidly administered mTBI screening test with results that are easily interpreted by providers is essential in making return-to-duty decisions in the injured warfighter.

### Summary Points:

- ✓ King-Devick (KD) test was studied as screening tool in 200 Army warfighters.
- ✓ Significant KD cumulative time differences between acute mTBI and control groups. The K-D Test showed a little more than one-third slower reading time in the mTBI group.
- ✓ Strong test-retest reliability in KD tests in both groups.
- ✓ Results suggest acquiring KD baseline tests prior to deployment/training.
- ✓ Having a validated, rapid, easy-to-assess mTBI brain screening test can assist frontline providers in making the return-to-duty (RTD) decision to send the warfighter back to the “fight”, or to a higher echelon of care for more comprehensive tests.



J Neurol Sci. 2015;357(1-2):75-9.

### **Use of the King-Devick Test for Sideline Concussion Screening in Junior Rugby League**

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**Aim:** To determine whether the King-Devick (K-D) test used as a sideline test in junior rugby league players over 12 matches in a domestic competition season could identify witnessed and incidentally identified episodes of concussion. **Methods:** A prospective observational cohort study of a club level junior rugby league team ( $n=19$ ) during the 2014 New Zealand competition season involved every player completing two pre-competition season baseline trials of the K-D test. Players removed from match participation, or who reported any signs or symptoms of concussion were assessed on the sideline with the K-D test and referred for further medical assessment. Players with a pre- to post-match K-D test difference  $>3$  s were referred for physician evaluation. **Results:** The baseline test-retest reliability of the K-D test was high ( $rs=0.86$ ;  $p<0.0001$ ). Seven concussions were medically identified in six players who recorded pre to post-match K-D test times greater than 3 s (mean change of 7.4 s). Post-season testing of players demonstrated improvement of K-D time scores consistent with learning effects of using the K-D test (67.7 s vs 62.2 s). **Discussion:** Although no witnessed concussions occurred during rugby play, six players recorded pre to post-match changes with a mean delay of 4 s resulting in seven concussions being subsequently confirmed post-match by health practitioners. All players were medically managed for a return to sports participation. **Conclusion:** The K-D test was quickly and easily administered making it a practical sideline tool as part of the continuum of concussion assessment tools for junior rugby league players.

### Summary Points:

- ✓ Evaluated the K-D test for screening concussion in youth rugby players ages 9-10.
- ✓ Routine post-match screening with K-D test identified 6 unwitnessed, unreported concussions that were later diagnosed by a physician.
- ✓ The K-D test demonstrated high test-retest reliability at baseline in this cohort of junior rugby players.
- ✓ The K-D test is an effective tool to determine if a player should be removed from play and referred to a physician for further evaluation.

## Evaluation of the King-Devick Test as a Concussion Screening Tool in High School Football Players

Seidman DH, Burlingame J, Yousif LR, Donahue XP, J Krier, Rayers LJ, Young R, Lilla M, Mazurek R, Hittle K, McCloskey C, Misra S, Shaw MK

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**Objective:** Concussion is the most common type of traumatic brain injury, and results from impact or impulsive forces to the head, neck or face. Due to the variability and subtlety of symptoms, concussions may go unrecognized or be ignored, especially with the pressure placed on athletes to return to competition. The King-Devick (K-D) test, an oculomotor test originally designed for reading evaluation, was recently validated as a concussion screening tool in collegiate athletes. A prospective study was performed using high school football players in an attempt to study the K-D as a concussion screening tool in this younger population. **Methods:** 343 athletes from four local high school football teams were recruited to participate. These athletes were given baseline K-D tests prior to competition. Individual demographic information was collected on the subjects. Standard team protocol was employed to determine if a concussion had occurred during competition. Immediately after diagnosis, the K-D test was re-administered to the concussed athlete for comparison to baseline. Post-season testing was also performed in non-concussed individuals. **Results:** Of the 343 athletes, nine were diagnosed with concussions. In all concussed players, cumulative read times for the K-D test were significantly increased ( $p < 0.001$ ). Post-season testing of non-concussed athletes revealed minimal change in read times relative to baseline. Univariate analysis revealed that history of concussion was the only demographic factor predictive of concussion in this cohort. **Conclusion:** The K-D test is an accurate and easily administered sideline screening tool for concussion in adolescent football players.

### Summary Points:

- ✓ 343 high school football athletes completed pre-season baseline K-D test.
- ✓ The K-D test was administered promptly after the on-field concussion diagnosis for comparison to baseline.
- ✓ Nine players were diagnosed with a concussion during season.
- ✓ Sideline K-D test times were significantly worse compared to baseline among concussed players.
- ✓ K-D Test scores in non-concussed athletes showed a minimal improvement from pre- to post-season.
- ✓ No non-concussed athletes increased or worsened K-D test time compared to baseline, which supports the instruction that any increase in K-D test time is indicative of a concussion.

## Objectifying eye movements during rapid number naming: Methodology for assessment of normative data for the King-Devick test

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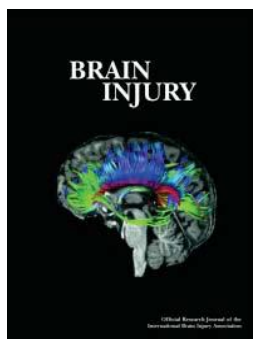
**Objective:** Concussion is a major public health problem and considerable efforts are focused on sideline-based diagnostic testing to guide return-to-play decision-making and clinical care. The King-Devick (K-D) test, a sensitive sideline performance measure for concussion detection, reveals slowed reading times in acutely concussed subjects, as compared to healthy controls; however, the normal behavior of eye movements during the task and deficits underlying the slowing have not been defined. **Methods:** Twelve healthy control subjects underwent quantitative eye tracking during digitized K-D testing. **Results:** The total K-D reading time was 51.24 ( $\pm 9.7$ ) seconds. A total of 145 saccades ( $\pm 15$ ) per subject were



generated, with average peak velocity 299.5 degrees/sec and average amplitude 8.2 degrees. The average inter-saccadic interval was 248.4 msec. Task-specific horizontal and oblique saccades per subject numbered, respectively, 102 ( $\pm 10$ ) and 17 ( $\pm 4$ ). Subjects with the fewest saccades tended to blink more, resulting in a larger amount of missing data; whereas, subjects with the most saccades tended to make extra saccades during line transitions. **Conclusions:** Establishment of normal and objective ocular motor behavior during the K-D test is a critical first step towards defining the range of deficits underlying abnormal testing in concussion. Further, it sets the groundwork for exploration of K-D correlations with cognitive dysfunction and saccadic paradigms that may reflect specific neuroanatomic deficits in the concussed brain.

### Summary Points:

- ✓ There is a concussion epidemic among athletes, and this extends to military personnel and other population groups.
- ✓ Given the widespread distribution of the visual pathways throughout the brain, a sideline test incorporating vision may aid in the diagnosis of concussion.
- ✓ The King-Devick (K-D) test, a rapid vision-based performance measure of rapid number naming, has been examined in a range of athletes at different ages and may be useful in the identification of concussion.
- ✓ Any worsening of baseline K-D test time at the time of an injury indicates a 5× greater risk of concussion.



Brain Injury. 2018;32(2):200-208.

### **Validity of low-resolution eye-tracking to assess eye movements during a rapid number naming task: performance of the eyetribe eye tracker**

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**Objective:** To evaluate the performance of the EyeTribe compared to the EyeLink for eye movement recordings during a rapid number naming test in healthy control participants. **Background:** With the increasing accessibility of portable, economical, video-based eye trackers such as the EyeTribe, there is growing interest in these devices for eye movement recordings, particularly in the domain of sports-related concussion. However, prior to implementation there is a primary need to establish the validity of these devices. One current limitation of portable eye trackers is their sampling rate (30–60 samples per second, or Hz), which is typically well below the benchmarks achieved by their research-grade counterparts (e.g., the EyeLink, which samples at 500–2000 Hz). **Methods:** We compared video-oculographic measurements made using the EyeTribe with those of the EyeLink during a digitized rapid number naming task (the King-Devick test) in a convenience sample of 30 controls. **Results:** EyeTribe had loss of signal during recording, and failed to reproduce the typical shape of saccadic main sequence relationships. In addition, EyeTribe data yielded significantly fewer detectable saccades and displayed greater variance of inter-saccadic intervals than the EyeLink system. **Conclusion:** Caution is advised prior to implementation of low-resolution eye trackers for objective saccade assessment and sideline concussion screening.

### Summary Points:

- ✓ King-Devick Test was used as the test of choice for this comparative study of two eye trackers (EyeLink 500-2000Hz) vs. EyeTribe 30-60Hz) due to the numerous studies demonstrating an increase in K-D test scores in athletes with concussion compared with baseline measures.
- ✓ There were significant quantitative differences between the data acquired by the two eye tracking systems with the most notable differences involving the overall qualitative characteristics of the results.

- ✓ Authors caution the use of low-resolution eye trackers due to frequent signal loss, eye movement data that did not appear to conform to any previously published pattern of results or normal ocular motor physiology, and significantly fewer saccades detected as a result of the low sampling rate.
- ✓ An additional consideration in the use of portable eye tracking systems in a sideline concussion screen is that the eye position data generated by such systems requires filtering, conversion and interpretation by computational scientists and other experts, expertise not typically available to athletic trainers, team physicians or sports parents.
- ✓ Findings demonstrate that care should be taken prior to implementation of commercially available, low-resolution, portable eye movement recording devices for use in obtaining objective ocular motor recordings.



J Neuroophthalmol. 2015;35(3):235-41.

### **Adding vision to concussion testing: A prospective study of sideline testing in youth and collegiate athletes**

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*Department of Athletics (NW), New York University, New York, NY; Department of Athletics, Long Island University, Brooklyn, NY; Departments of Emergency Medicine and Pediatrics, Cohen Children's Medical Center of New York, Hofstra North Shore LIJ School of Medicine (AS); Departments of Neurology (KMG, SLG, LJB) and Epidemiology (LJB), University of Pennsylvania, Philadelphia, PA, USA*

**Objective:** Sports-related concussion commonly affects the visual pathways. Current sideline protocols test cognition and balance, but do not include assessments of visual performance. We investigated how adding a vision-based test of rapid number naming could increase our ability to identify concussed athletes on the sideline at youth and collegiate levels.

**Methods:** Participants in this prospective study included members of a youth ice hockey and lacrosse league and collegiate athletes from New York University (NYU) and Long Island University (LIU). Athletes underwent pre-season baseline assessments using 1) the King-Devick (K-D) test, a <2-minute visual performance measure of rapid number naming; 2) the Standardized Assessment of Concussion (SAC), a test of cognition; 3) a timed tandem-gait test of balance. The SAC and timed tandem-gait are components of the currently used Sport-Concussion Assessment Tool, 3<sup>rd</sup> Edition (SCAT3 and Child-SCAT3). In the event of a concussion during the athletic season, injured athletes were re-tested on the sideline/ rink-side. Non-concussed athletes were also assessed as control participants under the same testing conditions. **Results:** Among 243 youth (mean age 11±3 years, range 5-17) and 89 collegiate athletes (age 20±1 years, range 18-23), baseline time scores for the K-D test were lower (better) with increasing participant age ( $p<0.001$ , linear regression models). Among 12 athletes who sustained concussions during their athletic season, K-D scores worsened from baseline by an average of 5.2 seconds; *improvement* by 6.4 seconds was noted for the non-concussed controls ( $n=14$ ). The vision-based K-D test showed the greatest capacity to distinguish concussed vs. control athletes based on changes from pre-season baseline to post-injury (ROC curve areas from logistic regression models, accounting for age=0.92 for K-D, 0.87 for timed tandem gait, and 0.68 for SAC;  $p=0.0004$  for comparison of ROC curve areas). **Conclusion:** Adding a vision-based performance measure to cognitive and balance testing enhances the detection capabilities of current sideline concussion assessment. This observation in mild traumatic brain injury patients reflects the common involvement and widespread distribution of the brain pathways dedicated to vision.

### Summary Points:

- ✓ The K-D test was validated in ages as young as 5
- ✓ K-D Sensitivity = 75%, K-D Specificity = 93%
- ✓ K-D shows the greatest capacity to distinguish concussed vs. non-concussed control groups based on changes from preseason baseline ROC curve areas
- ✓ Athletic trainers had a 92% probability of correctly distinguishing a concussed vs. non-concussed athletes based on the result of the K-D test alone (ROC curve areas from logistic regression models, accounting for age were K-D = 0.92, timed tandem gait = 0.87, and SAC = 0.68).

- ✓ The K-D test is a useful tool to aid in the diagnosis of concussed athletes at all levels of sport.
- ✓ Preseason baseline scores add to the simplicity and relevance of the K-D test in youth athletes and obviate the need for parents or others on the sideline to determine normative values in the acute setting of an injury.
- ✓ The combination of timed tandem gait, SAC and K-D resulted in a 97% ROC curve area.



Ann Sports Med Res. 2015;2(9): 1051.

### Agreement of the Spiral-Bound and Computerized Tablet Versions of the King-Devick Test of Rapid Number Naming for Sports Related Concussion.

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**Objective:** The purpose of this investigation was to measure levels of agreement and quantitate the relative differences in baseline scores between the two versions of the K-D test. **Background:** Sports-related concussions are an increasingly recognized public

health problem and may have serious neurologic implications for athletes. The vision-based King-Devick (K-D) test of rapid number naming has become an important tool to screen for concussion in athletes at the sidelines. Although the spiral-bound version of the K-D test has been tested in numerous research studies for this purpose, a computerized tablet-based version is now available. **Methods:** We recruited 85 participants into the study during sideline testing, and administered both the spiral and tablet versions of the K-D test to each participant. Version order was randomized to minimize the potential influences of learning effects on test differences. **Results:** There was excellent agreement (ICC=0.92, 95% CI: 0.82, 0.96) and strong linear correlations ( $r=0.94$ ) between the two test versions. However, the tablet version had a significantly longer mean pre-season baseline test time compared to the spiral version (52.3 seconds vs. 48.6 seconds,  $p<0.001$ , paired t-test). A difference of 3.7 seconds between the two test modalities may be clinically significant since acutely concussed athletes in published studies and meta-analyses show average increases of 4 to 6 seconds in the K-D test time from baseline. **Conclusions:** The computerized tablet and spiral-bound versions of the K-D test have excellent agreement, suggesting that the tablet version should also be good predictor of concussion. However, alternating between the tablet and spiral versions of the K-D test may be inaccurate when screening for concussion during sideline testing.

### Summary Points:

- ✓ The tablet and spiral bound K-D Test have excellent agreement
- ✓ The tablet version of the K-D Test is good predictor of concussion
- ✓ Users should not alternate between tablet and spiral versions of the K-D test



Clin J Sport Med. 2018; 00:1-4

### King-Devick Test Time Varies by Testing Modality

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Kinesiology, University of Georgia, Athens, GA; { {Department of Orthopaedic Surgery, University of Pittsburgh, Pittsburgh, PA; || || Department of Family Medicine, University of Washington, Seattle, WA; \*\*\*School of Kinesiology, University of Michigan, Ann Arbor, MI; †††Department of Neurosurgery, Medical College of Wisconsin, Milwaukee, WI; ‡‡‡Department of Psychiatry, Indiana

**Objective:** To explore differences in baseline King-Devick Test (KD) completion time between 2 testing modalities: (1) spiral-bound paper cards (cards) and (2) iPad application (iPad). **Design:** Cross-sectional cohort analysis. **Setting:** National Collegiate Athlete Association (NCAA) institutions. **Participants:** Student athletes from 13 women's and 11 men's collegiate sports who completed KD baseline testing as part of their first year in the Concussion Assessment, Research and Education (CARE) Consortium from 2014 to 2016 (n=2003, 52.2% male). **Independent Variables:** King-Devick Test modalities; cards or iPad. **Main Outcome Measure:** Baseline KD completion time (seconds). **Results:** Mean baseline KD completion time of the iPad modality group [42.8 seconds, 95% confidence interval (CI), 42.1-43.3] was 2.8 seconds (95%CI, 2.1-3.4) greater than the cards group (40.0 seconds, 95%CI, 39.7-40.3) (t(1, 1010.7)528.0, P,0.001, Cohen's d50.41). **Conclusions:** Baseline KD performance is slower when tested on an iPad than when tested on spiral-bound paper cards. The 2 KD modalities should not be used interchangeably in concussion assessments because differences in the modalities can lead to time differences similar in magnitude to those used to indicate concussion. From a research perspective, modality may influence interpretation and/or synthesis of findings across studies.

### Summary Points:

- ✓ The study supports the assertion that testing modalities should not be interchanged because differences from modality could lead to underdiagnosis (iPad baseline followed by cards postinjury) or overdiagnosis (cards baseline followed by iPad postinjury) of concussion.
- ✓ Clinicians should administer baseline and postinjury assessments using the same modality because differences in the modalities alone can lead to differences of time that are similar in magnitude to those used to indicate concussion.



J Neurol Sci. 2015;351(1-2):58-64.

### The King-Devick test was useful in management of concussion in amateur rugby union and rugby league in New Zealand

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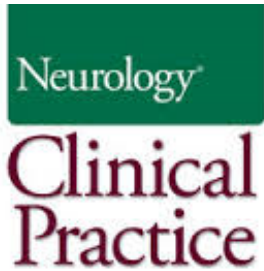
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**Aim:** To use the King-Devick (K-D) test in senior amateur rugby union and rugby league players over a domestic competition season to see if it could identify witnessed and unwitnessed episodes of concussion that occurred from participation in competition matches over three years. **Methods:** A prospective observational cohort study was conducted on a club level senior amateur rugby union team (n=36 players in 2012 and 35 players in 2013) and a rugby league team (n=33 players in 2014) during competition seasons in New Zealand. All 104 players completed two trials 10 minutes apart of the K-D at the beginning of their competition season. Concussions (witnessed or unwitnessed) were only recorded if they were formally diagnosed by a health practitioner. **Results:** A total of 52 (8 witnessed; 44 unwitnessed) concussive events were identified over the duration of the study resulting in a concussion injury incidence of 44 (95% CI: 32 to 56) per 1,000 match participation hours. There was a six-fold difference between witnessed and unwitnessed concussions recorded. There were observable learning effects observed between the first and second K-D test baseline testing (50 vs. 45 s; z=-8.81; p<0.001). For every 1 point reduction in each of the post-injury SAC components there was a corresponding increase (worsening) of K-D test times post-match for changes in orientation (2.9 s), immediate memory (1.8 s) concentration (2.8 s), delayed recall (2.0 s) and SAC total score (1.7 s). **Discussion:** The rate of undetected concussion was higher than detected concussions by using the K-D test routinely following matches. Worsening of the K-D test post-match was associated with reduction in components of the SAC. The appeal of the K-D test is in the rapid, easy manner of its administration and the reliable, objective results it provides to the administrator. The K-D test helped identify cognitive impairment in players without clinically observable symptoms.



### Summary Points:

- ✓ Routine post-match screening with K-D test identified 44 unwitnessed, unreported concussions over the duration of the study, and 6 times more than the 8 witnessed concussions identified pitch-side.
- ✓ K-D Sensitivity = 100%, K-D Specificity = 94%
- ✓ K-D scores correlated with SAC for players with concussive injury.
- ✓ By using a return to play monitoring process with the K-D test, the team medic was able to identify players that could commence graduated return-to-play activities while still monitoring the player's recovery.
- ✓ A composite of rapid brief test such as the K-D test, the SAC and the BESS are likely to provide a series of effective clinical tools to assess players on the sideline with a suspected concussive injury.



Neurol Clin Pract. 2014.

### **Vision Testing is Additive to the Sideline Assessment of Sports-Related Concussion**

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We examined the King-Devick (K-D) test, a vision-based test of rapid number naming, as a complement to components of the Sport Concussion Assessment Tool, 3<sup>rd</sup> edition (SCAT3) for diagnosis of concussion. Baseline and post-concussion data for the University of Florida men's football, women's soccer and women's lacrosse teams were collected, including K-D test, Standardized Assessment of Concussion (SAC) and Balance Error Scoring System (BESS). Among 30 athletes with first concussion during their athletic season (n=217 total), differences from baseline to post-injury showed worsening of K-D time scores in 79%, while SAC showed a  $\geq 2$ -point worsening in 52%. Combining K-D and SAC captured abnormalities in 89%; adding the BESS identified 100% of concussions. Adding a vision-based test may enhance the detection of athletes with concussion.

### Summary Points:

- ✓ In this retrospective analysis of collegiate athletes at the University of Florida, 79% of concussed athletes showed worsening of K-D test scores from baseline while SAC worsening was seen in 52%.
- ✓ Combining K-D Test with SAC and BESS identified 100% of concussions.
- ✓ The K-D test, a visual test that measures neurological dysfunction not captured by cognitive or balance tests is additive to the sideline concussion evaluation.
- ✓ Worse K-D scores were associated with reduced ImPACT visual motor speed and visual memory and worse SAC scores.
- ✓ The brain pathways for eye movements are widely distributed and involved the frontal eye fields, supplementary eye field, dorsolateral prefrontal cortex, parietal lobes, and deeper structures including the brainstem - all areas that are susceptible to injury in concussion.
- ✓ Data from the study demonstrate the additive effect of using multiple sideline tools that examine a wide range of neurologic dysfunction; while cognitive and balance tests were normal in certain subjects, a visual test, the K-D test, showed abnormalities.
- ✓ Adding a test that captures saccadic eye movements as well as other aspects of visual function adds a critical dimension to post-injury assessment in concussion.

## The King-Devick test as a determinant of head trauma and concussion in boxers and MMA fighters

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CC, Maguire MG, Messner LV, Devick S, Galetta SL, Balcer LJ

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**Objective:** Sports-related concussion has received increasing attention as a cause of short- and long-term neurologic symptoms among athletes. The King-Devick (K-D) test is based on measurement of the speed of rapid number naming (reading aloud single-digit numbers from 3 test cards), and captures impairment of eye movements, attention, language, and other correlates of suboptimal brain function. We investigated the K-D test as a potential rapid sideline screening for concussion in a cohort of boxers and mixed martial arts fighters. **Methods:** The K-D test was administered prefight and postfight. The Military Acute Concussion Evaluation (MACE) was administered as a more comprehensive but longer test for concussion. Differences in postfight K-D scores and changes in scores from prefight to postfight were compared for athletes with head trauma during the fight vs those without. **Results:** Postfight K-D scores ( $n = 39$  participants) were significantly higher (worse) for those with head trauma during the match ( $59.1 \pm 7.4$  vs  $41.0 \pm 6.7$  seconds,  $p < 0.0001$ , Wilcoxon rank sum test). Those with loss of consciousness showed the greatest worsening from prefight to postfight. Worse postfight K-D scores ( $r(s) = -0.79$ ,  $p = 0.0001$ ) and greater worsening of scores ( $r(s) = 0.90$ ,  $p < 0.0001$ ) correlated well with postfight MACE scores. Worsening of K-D scores by  $\geq 5$  seconds was a distinguishing characteristic noted only among participants with head trauma. High levels of test-retest reliability were observed (intraclass correlation coefficient 0.97 [95% confidence interval 0.90-1.0]). **Conclusions:** The K-D test is an accurate and reliable method for identifying athletes with head trauma, and is a strong candidate rapid sideline screening test for concussion.

### Summary Points:

- ✓ The K-D test is an accurate and reliable method for identifying athletes with head trauma.
- ✓ High degrees of test-retest reliability for the K-D were noted in this study (ICC=0.97).
- ✓ In the absence of concussion, athletes demonstrated improvement of K-D scores post-fight.
- ✓ Post-fight K-D time scores were worse for participants who had head trauma during their matches.
- ✓ Post-fight K-D times scores correlated with the Military Acute Concussion Evaluation (MACE) scores.
- ✓ The K-D test is based on measurement of speed or rapid number naming.
- ✓ The K-D test captures many aspects of neurological function including eye movements, attention, language.
- ✓ The K-D test may help coaches and trainers with game decisions regarding removal of a players who may have been concussed

## Saccades and Memory: Baseline associations of the King-Devick and SCAT2 SAC tests in professional hockey players

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**Objectives:** The Sports Concussion Assessment Tool 2 (SCAT2) and King-Devick (K-D) tests have both been proposed as sideline tools to detect sports-related concussion. We performed an exploratory analysis to determine the relation of SCAT2 components, particularly the Standardized Assessment of Concussion (SAC), to K-D test scores in a professional ice hockey team cohort during pre-season baseline testing. We also examined changes in scores for two athletes who developed concussion and had rinkside testing. **Methods:** A modified SCAT2 (no balance testing) and the K-D test, a brief measure of rapid number naming, were administered to 27 members of a professional ice hockey team during the 2011–

2012 pre-season. Athletes with concussion also underwent rinkside testing. **Results:** Lower (worse) scores for the SCAT2 SAC Immediate Memory Score and the overall SAC score were associated with greater (worse) times required to complete the K–D test at baseline. On average, for every 1-point reduction in SAC Immediate Memory Score, we found a corresponding increase (worsening) of K–D time score of 7.3 s (95% CI 4.9, 9.7,  $p=0.001$ ,  $R^2=0.62$ , linear regression, accounting for age). For the overall SAC score, 1-point reductions were associated with K–D score worsening of 2.2 s (95% CI 0.6, 3.8,  $p=0.01$ ,  $R^2=0.25$ , linear regression). In two players tested rinkside immediately following concussion, K–D test scores worsened from baseline by 4.2 and 6.4 s. These athletes had no differences found for SCAT2 SAC components, but reported symptoms of concussion. **Conclusions:** In this study of professional athletes, scores for the K–D test, a measure for which saccadic (fast) eye movements are required for the task of rapid number naming, were associated with reductions in Immediate Memory at a pre-season baseline. Both working memory and saccadic eye movements share closely related anatomical structures, including the dorsolateral prefrontal cortex (DLPFC). A composite of brief rapid sideline tests, including SAC and K–D (and balance testing for non-ice hockey sports), is likely to provide an effective clinical tool to assess the athlete with suspected concussion.

### Summary Points:

- ✓ Worse scores for the SCAT2 Immediate Memory Score and the overall SAC score were associated with worse times required to complete the K-D test as baseline.
- ✓ Several cortical areas are involved in the production and regulation of saccadic eye movements.
- ✓ Investigations of the DLPFC, known as the highest cortical area responsible for motor planning and working memory, have established the link with anticipatory saccades, a type of eye movement necessary for rapid number naming tasks as the K-D test.
- ✓ In two players tested rink-side immediately following concussion, K-D test scores worsened from baseline. For SCAT2 SAC components, however, these athletes showed no differences between baseline and rink-side concussion testing despite the fact that both athletes reporting new symptoms at the time of head trauma.
- ✓ A composite of brief rapid sideline tests, including SAC and K-D (and balance testing for non-ice hockey sports), is likely to provide an effective clinical tool to assess the athletes with suspected concussion.



J Neurol Sci. 2012 Sept; 320(1-2):16-21.

### **Use of a rapid visual screening tool for the assessment of concussion in amateur rugby league: a pilot study**

King D, Clark T, Gissane C. ; *Sports Performance Research Institute New Zealand, School of Sport and Recreation, Faculty of Health and Environmental Science, Auckland University of Technology, New Zealand.*

**Aim:** This study undertook to use the K-D sideline test with the SCAT2 to see if concussions could be identified in amateur rugby league players over a representative competition period. **Methods:** A prospective cohort study was conducted on two teams participating in an amateur rugby league. All players were tested for signs of concussion utilizing the K-D test and players with longer times than their baseline scores undertook a further concussion assessment with the SCAT2. **Results:** Five athletes with suspected concussion were evaluated by K-D testing. Three concussions were associated with witnessed events during the matches and two athletes were identified by the team medic as having longer K-D time scores incidentally post-match compared to baseline. Post-match K-D scores for all concussed athletes were worse than baseline for those with reported or witnessed concussion events (7s; 5.0-7.1;  $p=0.025$ ) and for those identified incidentally ( $>5s$ ; 8.9-9.1s). Both groups also reported more symptoms on the PCSS (a part of the SCAT2) post-match. **Discussion:** In this rugby cohort, the K-D test was not only useful in identifying changes in players with witnessed head trauma, but in identifying changes in players with an un-witnessed suspected concussion.

*“The K-D test was able to identify players with a suspected concussion, players with a concussion that was not reported or witnessed. The ease-of-use of the K-D Test made it more acceptable to team management and players and, as it provided immediate feedback to the player and coach. The K-D Test served to provide support for the decision made by the team medic to rule out the player from further match participation.”*

### Summary Points:

- ✓ 50 players total, 3 witnessed concussions, and 2 found on routine post-match K-D testing.
- ✓ Players with concussions scored worse than their K-D baseline and reported more symptoms.
- ✓ The K-D test is a useful sideline screening test that is able to identify concussed players who have no apparent signs or symptoms.
- ✓ One player with epilepsy, scored 9.3 s longer than baseline following 2 reported seizures, which supports that the K-D test is sensitive to neurological changes.



J Neurol Sci. 2013 Mar; 326(1-2):59-63.

### **Concussions in amateur rugby union identified with the use of a rapid visual screening tool**

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*Recreation, Faculty of Health and Environmental Science, Auckland University of Technology, New Zealand; School of Sport, Health and Applied Science, St Mary's University College, Twickenham, Middlesex, United Kingdom*

**Aim:** To use the King-Devick (K-D) test and Sports Concussion Assessment Tool 2 (SCAT2) in amateur rugby union players to identify witnessed and unrecognised episodes of concussion that occurred from match participation. **Methods:** A prospective observational cohort study was conducted on a premier club level amateur rugby union team during the 2012 competition in New Zealand. Every player completed a pre-competition questionnaire on concussion history, a baseline PCSS and two trials of the K-D before they participated in any match activities. **Results:** For players reporting a concussion in the previous three years there was an average of  $4.0 \pm 2.8$  concussions per player. There were 22 concussive incidents recorded over the duration of the competition (46 per 1000 match hours). Five concussive incidents were witnessed (11 per 1000 match hours) and 17 unrecognised concussive incidents were identified with the K-D (37 per 1000 match hours). Witnessed concussions recorded, on average, a longer K-D on the day of injury ( $5.5 \pm 2.4$  s) than unrecognised concussions ( $4.4 \pm 0.9$  s) when compared with their baseline K-D. **Discussion:** The K-D was able to identify players that had not shown, or reported, any signs or symptoms of a concussion but who had meaningful head injury. The current rate of concussion reported was a ten-fold increase in previously reported concussion injury rates. This makes the K-D suitable for rapid assessment in a limited time frame on the sideline such as a five-minute window to assess and review suspected concussed players in rugby union.

### Summary Points:

- ✓ 22 concussive events occurred during competition, 5 were witnessed, 17 were unwitnessed and identified by K-D.
- ✓ The K-D Test identified concussed players who did not manifest any signs or symptoms of a concussion.
- ✓ No significant difference existed in witnessed and unrecognized concussions with SCAT2 testing.
- ✓ There was no significant correlation between SCAT2 and K-D scores.
- ✓ Witnessed concussed athletes had longer differences in K-D scores compared to unrecognized concussions (5.5 s vs 4.4 s).
- ✓ All non-injured players completed the modified repeat high intensity endurance test, then performed the K-D test after. Post-exercise K-D times were better than baseline demonstrating that physical fatigue does not worsen K-D scores in the absence of a concussion.



J Neurol Sci. 2011 Oct 15; 309(1-2):34-9.

### **The King-Devick test and sports-related concussion: study of a rapid visual screening tool in a collegiate cohort**



**Objective:** Concussion, defined as an impulse blow to the head or body resulting in transient neurologic signs or symptoms, has received increasing attention in sports at all levels. The King-Devick (K-D) test is based on the time to perform rapid number naming and captures eye movements and other correlates of suboptimal brain function. In a study of boxers and mixed martial arts (MMA) fighters, the K-D test was shown to have high degrees of test-retest and inter-rater reliability and to be an accurate method for rapidly identifying boxers and mixed martial arts fighters with concussion. We performed a study of the K-D test as a rapid sideline screening tool in collegiate athletes to determine the effect of concussion on K-D scores compared to a pre-season baseline. **Methods:** In this longitudinal study, athletes from the University of Pennsylvania varsity football, sprint football, and women's and men's soccer and basketball teams underwent baseline K-D testing prior to the start of the 2010-11 playing season. Post-season testing was also performed. For athletes who had concussions during the season, K-D testing was administered immediately on the sidelines and changes in score from baseline were determined. **Results:** Among 219 athletes tested at baseline, post-season K-D scores were lower (better) than the best pre-season scores (35.1 vs. 37.9s,  $P=0.03$ , Wilcoxon signed-rank test), reflecting mild learning effects in the absence of concussion. For the 10 athletes who had concussions, K-D testing on the sidelines showed significant worsening from baseline (46.9 vs. 37.0s,  $P=0.009$ ), with all except one athlete demonstrating worsening from baseline (median 5.9s). **Conclusion:** This study of collegiate athletes provides initial evidence in support of the K-D test as a strong candidate rapid sideline visual screening tool for concussion. Data show worsening of scores following concussion, and ongoing follow-up in this study with additional concussion events and different athlete populations will further examine the effectiveness of the K-D test.

### Summary Points:

- ✓ 219 collegiate football, female and male soccer and basketball players performed the K-D test pre-season and post-season. Athletes who suffered a concussion were tested immediately following trauma.
- ✓ Non-concussed athletes' post-season scores minimally improved from baseline due to learning effect.
- ✓ 10 players sustained concussions and had significantly worse scores on the K-D test from baseline with a median change of 5.9 seconds slower.
- ✓ In a fatigue trial, the men's basketball team was tested immediately after a scrimmage. They showed improved scores from baseline, demonstrating that the post-workout fatigue does not worsen K-D scores.



J Sports Med Phys Fitness, 2014; 54:70-7.

### **The King-Devick test as a concussion screening tool administered by sports parents**

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**Background:** Sports-related concussion has received increasing awareness due to short- and long-term neurologic sequelae seen among athletes. The King-Devick (K-D) test captures impairment of eye movements and other correlates of suboptimal brain function. We investigated the K-D test as a screening for concussion when administered by layperson sports parents in a cohort of amateur boxers. **Methods:** The K-D test was administered pre-fight and post-fight by laypersons masked to the head trauma status of each athlete. Matches were watched over by a ringside physician and boxing trainer. Athletes with suspected head trauma received testing with the Military Acute Concussion Evaluation (MACE) by the ringside physician to determine concussion status. Athletes sustaining concussion were compared to the athletes screened using the K-D test. **Results:** Post-fight K-D scores were lower (better) than the best baseline score (41.0 vs. 39.3 seconds,  $p = 0.34$ , Wilcoxon signed-rank test), in the absence of concussion. One boxer sustained a concussion as determined by the ringside physician. This boxer was accurately identified by the layperson K-D testers due to a worsening in K-D test compared to baseline (3.2 seconds) and an increased number of errors. High levels of test-retest reliability were observed (intraclass correlation coefficient 0.90 [95% CI 0.84 - 0.97]). Additionally, 6 boxers who participated in multiple bouts showed no worsening of

their K-D times further supporting that scores are not affected by the fatigue associated with sparring. **Conclusion:** The K-D test is a rapid sideline screening tool for concussion that can be effectively administered by non-medically trained laypersons.

### Summary Points:

- ✓ K-D test was administered by masked layperson sports parents in a cohort of 33 amateur boxers, pre- and post-fight.
- ✓ Post-fight K-D scores were lower than the best baseline (41 vs 39.3 s) in non-concussed boxers.
- ✓ One boxer was diagnosed with a concussion and had a worse K-D score compared to baseline (3.2 s slower, increased errors).
- ✓ Six boxers were tested after multiple bouts showed no worsening of their scores, supporting that scores are not affected by fatigue.



J Neurol Sci. 2013 Nov; 334(1-2):148-53

### **Comparison and Utility of King-Devick and ImPACT® Composite Scores in Adolescent Concussion Patients**

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The King-Devick (K-D) oculomotor test has recently been advocated for sideline diagnosis of concussion. Although, visual processing and performance are often impaired in concussion patients, the utility of K-D as a concussion diagnostic tool is not validated. **Purpose:** To examine the diagnostic value of K-D, by comparing K-D with post-concussion symptom scale (PCSS) and ImPACT® composite scores. We hypothesized that K-D would be correlated with visual motor speed/memory (VMS, VIS) and reaction time (RT), because all require cognitive visual processing. We also expected parallel changes in K-D and PCSS across recovery. **Methods:** Thirty-five concussed individuals (12-19 y; 18 female, 17 male) were evaluated with PCSS, ImPACT® composite and K-D scores over four clinical visits (V). **Results:** K-D times improved with each visit ( $\Delta V1-V2$ :  $7.86 \pm 11.82$ ;  $\Delta V2-V3$ :  $9.17 \pm 11.07$ ;  $\Delta V3-V4$ :  $5.30 \pm 7.87$  sec) and paralleled improvements in PCSS ( $\Delta V1-V2$ :  $8.97 \pm 20.27$ ;  $\Delta V2-V3$ :  $8.69 \pm 14.70$ ;  $\Delta V3-V4$ :  $6.31 \pm 7.71$ ), RT ( $\Delta V1-V2$ :  $0.05 \pm 0.21$ ;  $\Delta V2-V3$ :  $0.09 \pm 0.19$ ;  $\Delta V3-V4$ :  $0.03 \pm 0.07$ ) and VMS ( $\Delta V1-V2$ :  $-5.27 \pm 6.98$ ;  $\Delta V2-V3$ :  $-2.61 \pm 6.48$ ;  $\Delta V3-V4$ :  $-2.35 \pm 5.22$ ). Longer K-D times were associated with slower RT ( $r=0.67$ ;  $p<0.0001$ ) and lower VMS ( $r=-0.70$ ;  $p<0.0001$ ), respectively. **Conclusion:** Cognitive visual performance testing using K-D has utility in concussion evaluation. Validation would further establish K-D as an effective ancillary tool in longitudinal concussion management and research.

### Summary Points:

- ✓ 35 concussed athletes ages 12-24, underwent post-concussion symptom scale, ImPACT, and K-D testing over 4 clinical visits, 2.5-4 weeks between each visit.
- ✓ K-D Test performance improved with recovery and correlated with improvements in symptoms, reaction time, visual motor speed, verbal memory, and visual memory.
- ✓ K-D Test has utility in concussion evaluation and longitudinal management.



Research in Sports Medicine. 2018.

## Pre-season concussion assessment utilizing the King-Devick Test

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This study's objectives were to assess the test-retest reliability and concurrent validity of the King-Devick Test (KDT) during concussion screening and to analyze potential sport-specific differences in test performance across two sports. Two hundred and sixty-six high school male American football and soccer players recruited from four area high schools participated prior to the fall sports season. Main outcome measures included the KDT and Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT). KDT performance demonstrated significant correlations with the ImPACT visual motor speed composite scores, reaction time, Cognitive Efficiency Index and age. Significant baseline differences were noted on the KDT between football and soccer players. The KDT demonstrates concurrent validity with three neurocognitive domains on the ImPACT. Significant differences in baseline King-Devick Test scores were found between football and soccer players and may be related to the neurocognitive demands of the sport.

### Summary Points:

- ✓ Differences in KDT times between football and soccer players may potentially be attributed to motor demands associated with these sports and other factors. Individualize baselines and not normative data should be used for concussion assessment.
- ✓ Findings support concurrent validity of the KDT with other commonly used concussion cognitive assessment tools
- ✓ Immediate standardized oculomotor testing adds additional objective data to effectively discern neurocognitive changes on the sideline and remove an athlete from play.



Int J Sports Med. 2017.

## Concussion Recovery Phase Affects Vestibular and Oculomotor Symptom Provocation

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Vestibular and oculomotor testing is emerging as a valuable assessment in sport-related concussion (SRC). However, their usefulness for tracking recovery and guiding return-to-play decisions remains unclear. Therefore the purpose of this study was to evaluate their clinical usefulness for tracking SRC recovery. Vestibular and oculomotor assessments were used to measure symptom provocation in an acute group (n = 21) concussed ≤ 10 days, prolonged symptoms group (n = 10) concussed ≥ 16 days (median = 84 days), healthy group (n = 58) no concussions in > 6 months. Known-groups approach was used with three groups at three time points (initial, 2-week and 6-week follow-up). Provoked symptoms for Gaze-Stabilization (GST), Rapid Eye Horizontal (REH), Optokinetic Stimulation (OKS), Smooth-Pursuit Slow (SPS) and Fast (SPF) tests, total combined symptoms scores and near point convergence (NPC) distance were significantly greater at initial assessment in both injury groups compared to controls. Injury groups improved on the King-Devick test and combined symptom provocation scores across time. The acute group improved over time on REH and SPF tests, while the prolonged symptoms group improved on OKS. A regression model (REH, OKS, GST) was 90 % accurate discriminating concussed from healthy. Vestibular and ocular motor tests give valuable insight during recovery. They can prove beneficial in concussion evaluation given the modest equipment, training and time requirements. The current study demonstrates that when combined, vestibular and oculomotor clinical tests aid in the detection of deficits following a SRC. Additionally, tests such as NPC, GST, REH, SPS,

SPF OKS and KD provide valuable information to clinicians throughout the recovery process and may aid in return to play decisions.

### Summary Points:

- ✓ Three groups were compared and tested initially, and at a 2-week and 6-week follow-up which included: healthy subjects (n=58), subjects with an acute sports-related concussion (n=21), and another group with prolonged symptoms (n=10).
- ✓ Poor performance on the KD test may be a sign of diminished saccadic movement speed and/or cognitive and language processing.
- ✓ KD total time improved across time relative to the initial assessment at both 2 weeks ( $p=0.04$ ) and 6 weeks ( $p=0.002$ ) for the prolonged recovery group. The acute group did not significantly improve until the 6-week time point ( $p=0.001$ ).
- ✓ These findings suggest that a brief ocular-motor screen including K-D test can aid in the diagnostic process when evaluating for a suspected concussion. Moreover, repeating the same screening at regular intervals following an initial diagnosis of a concussion may aid in return to play protocol and track the healing process.



Athletic Training & Sports Health Care. 2017;9(4):177-183.

### **Effect of Fatigue on Ocular Motor Assessments**

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**Purpose:** To evaluate the effect of exertional fatigue on the scores of two ocular motor tests: the King-Devick (Mayo Clinic, Oakbrook Terrace, IL) and near point of convergence tests. **Methods:** Twenty physically active individuals participated in two sessions (control and fatigue) via a randomized crossover design. During the control session, outcome measures were assessed before and immediately following 20 minutes of rest. The experimental session outcome measures were assessed before and immediately following a 20-minute previously established physical activity fatigue protocol. **Results:** Analysis of variance testing indicated no significant group  $\times$  time interaction effect for near point of convergence ( $P = .864$ ) and King-Devick ( $P = .155$ ) testing. **Conclusions:** The results of this study suggest that fatigue from physical activity does not affect near point of convergence or King-Devick test scores. Therefore, there is a low risk of a false positive concussion diagnosis due to fatigue during immediate sideline evaluation using these ocular motor assessments.

### Summary Points:

- ✓ Immediate effects of fatigue as a result of an exercise protocol did not significantly affect King-Devick scores.
- ✓ This is concurrent with previous studies that examined the effect of fatigue on the King-Devick test after a basketball scrimmage, a basketball workout, or a short sprinting drill.
- ✓ In agreement with previous research, another finding was a mean improvement of 1 second that was noted during the experimental posttest of the King-Devick test exemplifying practice effects.
- ✓ Specificity in this study was 95% under conditions of acute fatigue.
- ✓ Sideline concussion evaluations are administered to athletes who are tired from playing their respective sport. Findings from this study demonstrate that, in a college-aged physically active population, the King-Devick test is unaffected by exertional fatigue and is an appropriate tool for assessing concussion under conditions of acute physical activity. Therefore, athletic trainers may perform these ocular motor assessments immediately after a suspected concussive event with low risk of a fatigue-induced false-positive result.



## Gender and age predict outcomes of cognitive, balance and vision testing in a multidisciplinary concussion center

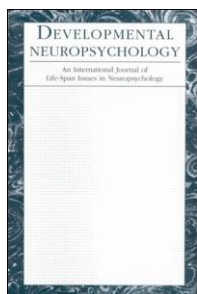
Peter A. Benedict, Natali V. Banerlemail, G. Kyle Harrold, Nicholas

Moehringer, Lisena Hasanaj, Liliana P. Serrano, Mara Sproul, Geraldine Pagnotta, Dennis A. Cardone, Steven R. Flanagan, Janet Rucker, Steven L. Galetta, Laura J. Balcer ; *Departments of Neurology, Population Health, Ophthalmology and Sports Medicine/Orthopaedic Surgery*

**Objective:** This study examined components of the Sports Concussion Assessment Tool, 3rd Edition (SCAT3) and a vision-based test of rapid number naming (King–Devick [K-D]) to evaluate sports and non-sports concussion patients in an outpatient, multidisciplinary concussion center. While the Symptom Evaluation, Standardized Assessment of Concussion (SAC), modified Balance Error Scoring System (BESS), and K-D are used typically for sideline assessment, their use in an outpatient clinical setting following concussion has not been widely investigated. **Methods:** K-D, BESS, SAC, and SCAT3 Symptom Evaluation scores were analyzed for 206 patients who received concussion care at the Concussion Center at NYU Langone Medical Center. Patient age, gender, referral data, mechanism of injury, time between concussive event and first concussion center appointment, and the first specialty service to evaluate each patient were also analyzed. **Results:** In this cohort, Symptom Evaluation scores showed a higher severity and a greater number of symptoms to be associated with older age ( $r = 0.31$ ,  $P = 0.002$ ), female gender ( $P = 0.002$ , t-test), and longer time between the concussion event and first appointment at the concussion center ( $r = 0.34$ ,  $P = 0.008$ ). Performance measures of K-D and BESS also showed associations of worse scores with increasing patient age ( $r = 0.32$ – $0.54$ ,  $P \leq 0.001$ ), but were similar among males and females and across the spectrum of duration since the concussion event. Patients with greater Symptom Severity Scores also had the greatest numbers of referrals to specialty services in the concussion center ( $r = 0.33$ ,  $P = 0.0008$ ). Worse Immediate Memory scores on SAC testing correlated with slower K-D times, potentially implicating the dorsolateral prefrontal cortex as a commonly involved brain structure. **Conclusion:** This study demonstrates a novel use of sideline concussion assessment tools for evaluation in the outpatient setting, and implicates age and gender as predictors of outcomes for these tests.

### Summary Points:

- ✓ Examined the utility of SCAT3 symptoms evaluation, SAC, mBESS, and K-D tests as clinical tools to evaluate concussion patients ages 10-77 in an outpatient concussion center.
- ✓ Worse K-D Test and mBESS scores were associated with increasing age.
- ✓ Worse Immediate Memory scores on SAC testing correlated with slower K-D times.
- ✓ Worse K-D scores were associated with higher symptom severity scores.
- ✓ The dorsolateral prefrontal cortex involves working memory, saccadic function, motor planning, and emotional control, which may, in part, explain the correlation.



Developmental Neuropsychology. 2015, 40:1, 7-11.

## Oculomotor and Neurocognitive Assessment of Youth Ice Hockey Players: Baseline Associations and Observations After Concussion

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Baseline scores on the King-Devick (K-D) Test, Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), Sport Concussion Assessment Tool 3 (SCAT3), and convergence were evaluated in youth hockey players. Worse K-D times were associated with worse ImPACT visual motor speed and reaction time. Eleven concussed athletes were retested, and there was a trend toward improved ImPACT and K-D times compared to baseline.

### Summary Points:

- ✓ Previous studies have shown an association between baseline K-D times and SCAT2 memory scores.
- ✓ This link between saccadic function and working memory may be due to co-localization of these functions within the dorsolateral prefrontal cortex.
- ✓ In this study, worse K-D times were associated with worse ImPACT visual motor speed and reaction time subtests.
- ✓ The injured subset received post-injury assessments, on average, 109 days after baseline testing and generally did not show worsening of ImPACT, SCAT3 memory, or K-D times post-injury, reflecting either continued developmental gains in these domains or a learning effect.
- ✓ This study supports the use of multiple assessment tools in the comprehensive clinical evaluation of pediatric concussion.

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### **Sideline concussion testing in high school football on Guam**

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**Background:** The risks of repeat concussions and returning to play (RTP) prior to the resolution of concussive symptoms are medically established. However, RTP guidelines for high school sports are varied and often notably absent. The island of Guam, a US territory, has a robust athletics program but lacks structure to reduce concussions or establish RTP protocols. Consequently, there is an opportunity to limit the incidence of "second-hit syndrome" and other harmful effects through education and testing. **Methods:** We evaluated the feasibility of Sideline Concussion Testing (SCT) as a novel feature of Guam high school athletics. Thirteen high school football players were observed over three consecutive football games. They were first given a questionnaire about concussion history, symptoms, medical evaluation, and RTP. Researchers used the King-Devick Test, a SCT tool, and baseline scores were recorded. If players were then observed to have significant head trauma or to show concussive symptoms, they were sidelined and tested. **Results:** Five of 13 students had a previous concussion and limited awareness of RTP guidelines. Of those five, four received no medical consultation or stand down period before RTP. There was also a lack of understanding of what constitutes a concussion; five out of eight individuals who denied previous concussion confirmed having bell ringers, seeing stars, and other classic concussive symptoms. Over the course of the study the SCT identified three concussions, with significant deviations from baseline time on a test that measured visual and speech disturbances. **Conclusions:** The feasibility of SCT use in Guam high school football was established and our pilot study identified areas for improvement. Established definitions of concussion and RTP guidelines were lacking. Therefore, an opportunity exists through public health efforts that involve the entire community to increase concussion awareness and reduce injuries in high school sports on Guam.

### Summary Points:

- ✓ High school football players completed a questionnaire, listed symptoms, underwent medical examination, and performed the K-D Test baseline and repeated if head injury occurred during any of 3 games.
- ✓ The K-D Test detected 3 concussed athletes with significant deviations (5-8 s worse) than baseline K-D scores and showed several concussion symptoms.
- ✓ As concussed players resolved after 1-2 weeks post-concussion, K-D scores improved.

- ✓ Established sideline concussion testing would greatly improve the lack of concussion protocol and concussion awareness.



J Child Neurol. 2014 Dec;29(12):1601-7.

## Effects of Youth Football on Selected Clinical Measures of Neurologic Function: A Pilot Study

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We assessed 10 youth football players (13.4 + 0.7 y) immediately before and after their season to explore the effects of football participation on selected clinical measures of neurologic function. Postseason postural stability in a closed-eye condition was improved compared to preseason (P 1/4 .017). Neurocognitive testing with the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) battery revealed that reaction time was significantly faster at postseason (P 1/4 .015). There were no significant preseason versus postseason differences in verbal memory (P 1/4 .507), visual memory (P 1/4 .750), or visual motor speed (P 1/4 .087). Oculomotor performance assessed by the King-Devick test was moderately to significantly improved (P 1/4 .047-.115). A 12-week season of youth football did not impair the postural stability, neurocognitive function, or oculomotor performance measures of the players evaluated. Though encouraging, continued and more comprehensive investigations of this at-risk population are warranted.

### Summary Points:

- ✓ 10 non-concussed youth football players underwent postural stability testing, ImPACT, K-D testing pre- and post-season.
- ✓ Postseason postural stability (Eyes closed portion), Reaction time of ImPACT, and K-D scores significantly improved compared to pre-season testing.
- ✓ There were no impairments in neurologic function according to the selected tests following 12 weeks of football.
- ✓ Improvements in oculomotor performance are due to a learning effect and a possible result of development of more advanced oculomotor skills in this specific age group over time.



J Optom. 2015 Jan 31. pii:S1888-4296(14)00116-2.

## The King-Devick test for Sideline Concussion Screening in Collegiate Football

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**Purpose:** Sports-related concussion has received increasing attention as a result of neurologic sequelae seen among athletes, highlighting the need for a validated, rapid screening tool. The King-Devick (K-D) test requires vision, eye movements, language function and attention in order to perform and has been proposed as a promising tool for assessment of concussion. We investigated the K-D test as a sideline screening tool in a collegiate cohort to determine the effect of concussion. **Methods:** Athletes (n = 127, mean age 19.6 ± 1.2 years) from the Wheaton College football and men's and women's basketball teams underwent baseline K-D testing at pre-season physicals for the 2012–2013 season. K-D testing was administered immediately on the sidelines for football players with suspected head injury during regular games and changes compared to baseline were determined. Post-season testing was also performed to compare non-concussed athletes' test performance. **Results:** Concussed athletes (n = 11) displayed sideline K-D scores that were significantly higher (worse) than baseline (36.5 ± 5.6 s vs. 31.3 ± 4.5 s, p < 0.005, Wilcoxon signed-rank test). Post-season testing demonstrated improvement of scores and was consistent with known learning effects (35.1 ± 5.2 s vs. 34.4 ± 5.0 s, p < 0.05, Wilcoxon

signed-rank test). Test-retest reliability was analyzed between baseline and post-season administrations of the K–D test resulting in high levels of test-retest reliability (intraclass correlation coefficient (ICC) = 0.95 [95% Confidence Interval 0.85–1.05]). **Conclusions:** The data show worsening of K–D test scores following concussion further supporting utility of the K–D test as an objective, reliable and effective sideline visual screening tool to help identify athletes with concussion.

### Summary Points:

- ✓ The K-D Test was assessed in collegiate basketball (female and male) and football.
- ✓ 11 out of 127 athletes had a concussion and significantly worse scores on K-D Test; 2 of the 11 concussed athletes passed the SCAT2, yet scored 4.9 s worse on K-D Test compared to baseline.
- ✓ Post-season testing showed high test-retest reliability and improved scores on K-D Test.
- ✓ K-D Test scores improved after a 2.5 h workout in non-concussed male and female basketball players.
- ✓ There was no worsening of K-D scores following physical fatigue in the absence of concussion.
- ✓ The K-D Test is a reliable, objective concussion screening tool that is not affected by physical fatigue or exercise.



The Sport Journal. 2014 March 12.

### **Baseline Concussion Testing in Different Environments: A Pilot Study**

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*United States Sports Academy*

**Purpose:** Athletic trainers and sport medicine professionals have the responsibility of diagnosing and managing concussion in athletes. The King-Devick (K-D) Test provides athletic trainers and sport medicine professionals with an easy-to-use concussion screening tool that requires only two minutes to administer and has relevance to contact sports such as football, soccer, boxing, and mixed martial arts. The purpose of this pilot study was to examine the reliability of baseline testing with the K-D Test in different environments.

**Methods:** A total of nine participants (6 males, 3 females, mean age:  $39 \pm 14.49$  yrs) participated in the three day investigation. Subjects reported to the human performance laboratory on three separate days. Participants were given standard instructions for the K-D Test. Participants were required to complete the K-D test under a quiet environment (with minimal to no noise) and under two loud (noisy) environments; one with speakers and the other with headphones.

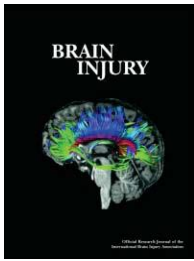
**Results:** Results indicated K-D scores for baseline (BL) and speakers (SP) rendered group means of (BL:  $40.54 \pm 14.95$  s, SP:  $40.54 \pm 15.92$  s), while scores for HP signified slightly lower group means of  $39.54 \pm 14.39$  s. No variables showed any statistical difference in K-D scores ( $P > 0.05$ ).

**Conclusion:** Most participants were able to improve their K-D scores from Trial 1 (T1) to Trial 2 (T2) on baseline testing, signifying a slight learning effect within the study group. **Application to Sport:** Athletic trainers, healthcare professionals, and those administering the K-D Test should be consistent in assessing pre and post K-D scores, although significant changes might not occur when performing the K-D Test under different environments (with crowd noise). Athletes should be treated on an individual basis when using the K-D Test to assess pre and post test scores.

### Summary Points:

- ✓ Tested the reliability of the King-Devick Test in quiet and loud (game noise) environments
- ✓ There is a slight learning effect when performing K-D Test Baseline scores.
- ✓ Noise did not significantly impact K-D Test performance.
- ✓ The K-D Test is reliable in both indoor quiet setting and a noisy game environment.





Brain Injury. 2017 November 8.

## **Baseline King–Devick scores for adults are not generalizable; however, age and education influence scores**

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**Objective:** To establish normative values for the King–Devick (K–D) test to be used as a reference for determining impairment related to concussion when individual baseline scores are lacking. **Method:**

Baseline K–D scores were collected for 243 participants aged 18–86. Results: The mean age of subjects was 40.46; range 18–86 years. The mean time was 42.2 seconds; 26.19–75.96 seconds. There was a relationship ( $r = 0.376$ ) between K–D score and age; scores increased (worsened) with age. There was also a relationship between score and education with scores decreasing as education increased ( $r = -0.194$ ;  $p = 0.002$ ). The K–D score was not influenced by sex or concussion history. A regression equation using education and age to predict K–D time explained 0.418 of the variance in K–D test time. **Conclusion:** Although this research established a relationship between K–D score and age and education, the range in scores was too broad to establish normative values. In the absence of a baseline score, the use of a regression equation considering age and education level may provide some indication of expected score. However, the most reliable use of the test as a screen for impairment following concussion involves the use of a baseline test.

### Summary Points:

- ✓ King-Devick test scores ranged from 26.19 to 75.96 seconds, for ages 18 to 86, with a mean of 42.2 seconds (standard deviation of 8.7 seconds), which is consistent with other published data.
- ✓ There was a weak relationship between K-D test scores and age (Pearson's  $r = 0.376$ ,  $p = 0.000$ ). K-D test scores increased as age increased. This relationship was the most significant in persons of more than 50 years of age and progressed at a much steeper slope in subjects older than 70 years of age.
- ✓ There was a weak negative correlation between K-D test scores and education level (Pearson's  $r = -0.194$ ,  $p = 0.002$ ). K-D test scores decreased (were faster) as education level increased.
- ✓ In agreement with other studies, the researchers concluded that any increase in post-injury K-D test score, when compared to an established baseline score, supports the diagnosis of concussion.
- ✓ Additionally, it is recommended that the newer, electronic version of the K-D test should be utilized for testing. All subsequent K-D tests should be measured in the same version as the baseline testing (i.e. an electronic K-D test should not be compared to an older version spiral-bound test).
- ✓ The study concluded that further normative values would be helpful in assessing test performance when a baseline measure is not available however the most reliable use of the test as a screen for impairment following concussion involves the use of a baseline test.



Scand J Med Sci Sports. 2015 Jun;25(3):e327-30.

## **King-Devick test normative reference values for professional male ice hockey players**

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The King–Devick (K–D) test, a measure of processing speed, visual tracking, and saccadic eye movements, has shown promise as a supplemental screening test following concussion. However, limited normative data for this test have been published. The K–D test was administered to 185 professional ice hockey players as a preseason baseline test in seasons 2012–2013 and 2013–2014. Their average age was 23.8 years (median = 22.0 years, range = 16–40 years). The average K–D score was 40.0 s (SD = 6.1 s, range = 24.0–65.7 s). K–D test performance showed no association with age, education, or

the number of self-reported previous concussions in this sample. The association between trials 1 and 2 of the K-D test was good (ICC = 0.92, Pearson = 0.93). Normative values of the K-D test for professional male ice hockey players are reported. K-D test performance did not vary by age, education, or concussion history in this study.

*"Without a reliable baseline measurement, it is not possible to know if that score indicates a decline for that particular individual or not. Compared with the SCAT3, the test measures different aspects of functioning, so it may prove to have value as an additional method for assessing the acute effects of concussion."*

### Summary Points:

- ✓ K-D test performance did not vary by age, education, or the number of self-reported past concussions.
- ✓ Reliable baseline measurement is necessary to determine individual change in K-D test performance.



The Sport Journal. 2014 March 7.

### **A Countywide Program to Manage Concussions in High School Sports**

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*United States Sports Academy*

**Background:** With the national spotlight on concussions sustained in contact sports, this Countywide Concussion Program addresses the unique challenges presented to public and private high schools in order to increase concussion awareness, identification, and management. **Methods:** The Miami Concussion Model (MCM) was developed with a standard protocol that includes; formation of a task force of stakeholders, concussion education and training to coaches, athletic trainers, and athletes; baseline ImPACT™ testing, the facilitation of ‘return to play’ decisions with effective medical treatment, and the development and implementation of a concussion injury surveillance system. **Results:** The program has been successfully implemented in about 40 high schools in Miami-Dade County (MDC) over the last two years. The MCM provided baseline testing for 18,357 student-athletes, trained over 100 coaches and 40 athletic trainers, and most recently provided concussion education to high school football athletes. Since 2011, the concussion clinic has treated a total of 216 high school athletes and the surveillance system tracked 198 student athletes. **Conclusion:** The MCM aims to assist in the prevention of concussions, improve player safety limiting school liability by providing a countywide concussion management program. The program is funded primarily by private donations and the support of multiple stakeholders. With about 48 States passing concussion legislation, the MCM can be used as a model for other counties to address the need for a concussion management program. **Applications in Sport:** Schools with athletic programs need to implement a system to correctly manage and prevent concussive injuries both to protect their athletes and to minimize liability. The development of the MCM and protocol with the support of the leadership of the School Board allows for high schools to take a proactive approach in improving concussion management for their athletes.

*"In MDC, sideline assessment requirements include the Sports Concussion Assessment Tool 2 (SCAT2) and the King-Devick Test. The SCAT2 represents a standardized method of evaluating athletes aged 10 and older for concussion injuries through a series of cognitive questions and physical assessments."*

### Summary Points:

- ✓ The Miami Concussion Model (MCM) is implemented in 40 high schools in Miami-Dade County.
- ✓ MCM includes baseline testing for 18,357 athletes and trained 100 coaches and 40 athletic trainers.
- ✓ Sideline assessments used to verify a suspected concussion: King-Devick Test and Sports Concussion Assessment Tool 2 (SCAT2).
- ✓ The Model includes Education, Execution, and Evaluation, which was shown to be successful in this large-scale pilot study.
- ✓ The MCM standard protocol effectively increased the number of identified concussions.
- ✓ The MCM may be used as a model for other counties to implement a successful concussion management program.

## King-Devick performance following moderate and high exercise intensity bouts

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The King-Devick (K-D) test is a concise, noninvasive assessment of oculomotor and cognitive function that has been shown to detect sub-optimal brain performance following sports head trauma. Used in a number of sports as a sideline concussion assessment tool, the K-D test can be administered by non-medical personnel. However, the issue regarding the effect of exercise on K-D performance has not been fully explored. Using a randomized crossover design, this study aimed to compare the effect of two intensities of exercise on K-D performance. Twenty males ( $21.2 \pm 1.9$  years) completed the KD test prior to and after 15 min of either moderate (65% of age-predicted maximal heart rate) and high intensity (80% of age-predicted maximal heart rate) exercise bouts, separated by one week. Significant differences were found in working heart rate and ratings of perceived exertion consistent with exercise intensities. K-D performance did not change after moderate exercise, however a significant improvement (5.4%) was observed after high intensity exercise. Based upon these findings, it appears that high intensity exercise can influence test performance and administrators of the test need to be aware of the arousal state a player is prior to K-D test administration to ensure objective measurement.

### Summary Points:

- ✓ Our results concur with previous research, our findings showing improved K-D performance after the intense exercise.

## Test-Retest Reliability of the King-Devick Test in Elite Junior Olympic Youth Athletes

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Illinois College of Optometry, Indiana University School of Optometry

**Objective:** The importance of sports-related concussion identification has received increasing attention in both media and research due to the possible long-term neurological sequelae that may occur with repeated closed head injuries. The King-Devick (K-D) test is a screening test of rapid number naming that requires eye movements, language, attention and concentration to complete. The K-D test has been validated as a measure to determine concussion by identifying suboptimal brain function in athletes ranging from youth to professional levels. The purpose of this investigation is to determine the potential effects of age on K-D scores, applicability of the test in a youth population, and determine the test-retest reliability of the test in elite youth athletes.

**Method:** Fifty-four athletes (mean age 11.7, range 6-17 years) participating in the 2014 Amateur Athletic Union (AAU) Junior Olympic Games were baseline tested with the K-D test at the beginning of a sports vision screening and then again at the conclusion of the screening with approximately 30 minutes between the baseline test administrations. Baseline test administrations determined Baseline Scores as the fastest error-free time of two consecutive trials.

**Results:** A high level of test-retest reliability was observed between two baseline trials (ICC 0.89 [95% CI 0.85-0.95]). Similarly, there was a high test-retest reliability between the first baseline score (the best of two trials) and the retest baseline score (ICC 0.93 [95% CI 0.89-0.96]). K-D test time correlated with age as improved K-D scores (lower time) were associated with older athletes with an average decrease (improvement) of K-D score of 3.7 seconds for every 1 year increase in age (95% CI 2.5-5.0,  $p < 0.001$ ,  $R^2 = 0.50$ , linear regression).

**Discussion:** Results from this study validate that the K-D test has high test-retest reliability for young athletes, who are vulnerable to concussive injury. This study demonstrated an improvement in time with increased age, suggesting that baseline testing should be repeated at least annually. This test is a simple performance measure to help coaches, parents and medical personnel identify concussion on the sidelines, and a change in score from baseline should be an indication for removal from play. Ongoing studies are examining the effectiveness of the K-D test as a predictive tool to detect concussion in athletes in the youth and adolescent age.

### Summary Points:

- ✓ There is high test-retest reliability for the K-D Test in youth athletes.
- ✓ Faster K-D Test time correlated with increasing age.
- ✓ Baseline testing should be repeated at least annually.
- ✓ This test is a simple performance measure to help coaches, parents and medical personnel identify concussion on the sidelines, and a change in score from baseline should be an indication for removal from play.



J Athl Train. 2017;52(2).

## Test-Retest Reliability of the King-Devick Test in an Adolescent Population

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**Context:** The King-Devick (KD) test is a screening tool designed to assess cognitive visual impairments, namely saccadic rhythm, postconcussion. Test-retest reliability of the KD in a healthy adolescent population has not yet been established.

**Objective:** To investigate the overall test-retest reliability of the KD among a sample of healthy adolescents. Additionally, we sought to determine if sex and age influenced reliability. **Design:** Cross-sectional study. **Setting:** Secondary school.

**Patients or Other Participants:** Sixty-eight healthy adolescents, 41 boys (age =  $15.4 \pm 1.9$  years) and 27 girls (age =  $15.4 \pm 1.9$  years). **Main Outcome Measure(s):** Participants completed the KD (version 1) at 3 testing sessions (days 1, 30, and 45) following standard instructions. We recorded total time to complete the reading of 3 cards for each participant during each testing session. Two-way random-effects intraclass correlation coefficients (ICCs) using single measurements repeated over time and repeatability coefficients were calculated. Linear mixed models were used to determine whether differences existed at each testing time and to examine whether changes that took place among visits were different by sex or age. **Results:** Adolescents who completed the KD demonstrated acceptable reliability (ICC = 0.81; 95% confidence interval = 0.73, 0.87); however, the repeatability coefficient was large ( $\pm 8.76$  seconds). The sample demonstrated improvements between visits 1 and 2 (mean  $\pm$  standard error =  $4.3 \pm 0.5$  seconds,  $P < 0.001$ ) and between visits 2 and 3 ( $2.4 \pm 0.5$  seconds,  $P < 0.001$ ) for a total improvement of 6.7 seconds over

3 tests. No significant visit-by-sex or visit-by-age interactions were observed. **Conclusions:** Despite the ICC being clinically acceptable, providers using the KD test for serial assessment of concussion in adolescents should be cautious in interpreting the results due to a large learning effect. Incorporating multiple measures can ensure accurate detection of sport concussion.

### Summary Points:

- ✓ In our entire sample, the ICC revealed good test-retest reliability from day 1 to day 45
- ✓ Time to complete the KD test decreased at each visit.
- ✓ No difference in time to complete the test was demonstrated between sexes.
- ✓ At baseline, adolescents 15 years and younger took longer to complete the test than adolescents 16 and older.
- ✓ Evaluating changes or deficits in oculomotor function should be considered as part of the concussion-assessment process.
- ✓ The KD test is designed to screen changes in oculomotor function and has been introduced as a potential addition to the tests currently available to determine if an athlete has sustained an SC.
- ✓ A key advantage of the KD test is its ease of delivery, both in the collection of baseline data and as a rapid assessment tool postinjury. With practice, health care providers and in certain cases laypersons (eg, parents and coaches) can learn how to deliver the test.
- ✓ Established learning effects demonstrated by improvements in time to complete the KD test over time in a healthy sample of participants (adolescents and adults) have been reported by other investigators. Our findings in a healthy adolescent population are consistent with these results.



2017 May 13

## Neurological tests improve after Olympic-style boxing bouts: a pretournament and post-tournament study in the 2016 Women's World Boxing Championships

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Cummiskey<sup>6</sup> Jean-Paul Grabner von Rosenberg<sup>8</sup> David McDonagh<sup>6,8,9</sup>

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**Aim** To prospectively examine the neurocognitive, postural, dual-task and visual abilities of female Olympic-style boxers before and after participation in a tournament. **Methods** Sixty-one females completed the modified Balance Error Scoring System (mBESS), King-Devick test and 3 m timed-up-and-go test in single-task and dual-task conditions. A subset (n=31) completed the CogState computerised neurocognitive test. Initial testing was completed prior to the 2016 Women's World Boxing Championships; each participant repeated the testing protocol within a day of elimination. No participant sustained a concussion. Pretournament and posttournament performance variables were compared using paired t-tests or Wilcoxon signed-rank tests. **Results** Participants completed a mean of  $7.5 \pm 4.5$  rounds of Olympic-style boxing over 2–8 days. Posttournament scores were significantly lower than pretournament scores for total mBESS ( $2.2 \pm 1.9$  errors vs  $5.5 \pm 2.9$  errors,  $p < 0.001$ ,  $d = 1.23$ ) and King-Devick time ( $14.2 \pm 3.9$  s vs  $18.0 \pm 8.3$  s,  $p = 0.002$ ,  $d = 0.53$ ). Processing speed was significantly faster after the boxing tournament (maze chase task:  $1.39 \pm 0.34$  correct moves/second vs  $1.17 \pm 0.44$  correct moves/second,  $p = 0.001$ ,  $d = 0.58$ ). No significant changes across time were detected for the other obtained outcome variables. **Conclusions** Female boxers demonstrated either improvement or no significant changes in test performance after competing in an Olympic-style boxing tournament, relative to pretournament performance. As many of the test tasks were novel for the boxers, practice effects may have contributed to improved performance. When there is a short time frame between assessments, clinicians should be aware of potential practice effects when using ringside neurological tests.

### Summary Points:

- ✓ No concussions were diagnosed during the tournament and no boxers were stopped early due to a suspected concussion.
- ✓ K-D test performance was significantly faster after the tournament compared with before the tournament.



Neurol. 2017;88:1-4

## Feasibility and accuracy of teleconcussion for acute evaluation of suspected concussion

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**Objective:** To assess the feasibility and accuracy of telemedical concussion evaluations (teleconcussion) for real-time athletic sideline assessment of concussion, as such assessment may address the gap in access some populations of athletes have to providers with expertise in concussion evaluation. **Methods:** A cohort of 11 consecutive male collegiate football players with suspected concussion was assessed using Standardized Assessment of Concussion (SAC), King-Devick test (K-D), and modified Balance Error Scoring System (mBESS). A remote neurologist assessed each athlete using a telemedicine robot with real-time, 2-way audiovisual capabilities, while a sideline provider performed a simultaneous face-to-face assessment. After the assessment, a remove-from-play (RFP) determination was made. The remote and the face-to-face providers were blinded to each other's examination findings and RFP decision until the end of the assessment. **Results:** The teleconcussion and face-to-face SAC were in agreement 100% of the time (6/6; 95% confidence interval [CI] 54%–100%). The mean (SD) difference between remote and sideline K-D times was 0.7 (1.4) seconds. Remote and sideline K-D times were within a 3-second difference 100% of the time (11/11; 95% CI 72%–100%). Remote and sideline

mBESS scores were within 3 points 100% of the time (6/6; 95% CI 54%–100%). RFP decisions were in agreement 100% of the time (11/11; 95% CI 72%–100%). **Conclusions:** The aim of this study was to investigate the feasibility of teleconcussion for sideline concussion assessments. These data suggest a high level of agreement between remote and face-to-face providers with regard to examination findings and RFP determinations.

### Summary Points:

- ✓ The conclusions from these studies suggest that teleconcussion is an accurate tool that may be used throughout the course of an athlete's concussion care—from the hyperacute and acute stages (on the sideline or in the emergency department) through recovery (with clinical assessments of neurologic and neuropsychometric function paired with physical and cognitive rehabilitation).



JNS. 2019.

### **Premorbid migraine history as a risk factor for vestibular and oculomotor baseline concussion assessment in pediatric athletes**

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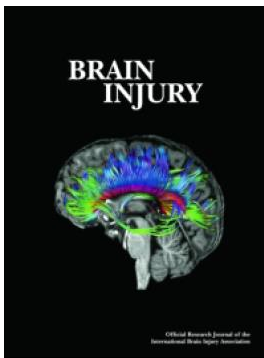
Injury Research Laboratory, Department of Kinesiology, Michigan State University, East Lansing, Michigan; and <sup>3</sup>Department of

Kinesiology and Sport Science, Youngstown State University, Youngstown, Ohio

**OBJECTIVE** Migraine history has recently been identified as a risk factor for concussion and recovery. The authors performed a cross-sectional study examining baseline outcome measures on newly developed and implemented concussion assessment tools in pediatrics. The purpose of this study was to examine the effects of premorbid, diagnosed migraine headaches as a risk factor on vestibular and oculomotor baseline assessment in pediatric athletes. **METHODS** Pediatric athletes between the ages of 8 and 14 years with a diagnosed history of migraine headache ( $n = 28$ ) and matched controls without a history of diagnosed migraine headache ( $n = 28$ ) were administered a baseline concussion assessment battery, consisting of the Vestibular/Ocular Motor Screening (VOMS), near point of convergence (NPC), and the King-Devick (K-D) tests. Between-groups comparisons were performed for vestibular symptoms and provocation scores on the VOMS (smooth pursuit, saccades, convergence, vestibular/ocular reflex, visual motion sensitivity), NPC (average distance), and K-D (time). **RESULTS** Individuals diagnosed with migraine headaches reported greater VOMS smooth pursuit scores ( $p = 0.02$ ), convergence scores ( $p = 0.04$ ), vestibular ocular reflex scores ( $p$  value range 0.002–0.04), and visual motion sensitivity scores ( $p = 0.009$ ). Differences were also observed on K-D oculomotor performance with worse times in those diagnosed with migraine headache ( $p = 0.02$ ). No differences were reported on NPC distance ( $p = 0.06$ ) or headache symptom reporting ( $p = 0.07$ ) prior to the VOMS assessment. **CONCLUSIONS** Pediatric athletes diagnosed with migraine headaches reported higher baseline symptom provocation scores on the VOMS. Athletes with migraine headaches also performed worse on the K-D test, further illustrating the influence of premorbid migraine headaches as a risk factor for elevated concussion assessment outcomes at baseline. Special consideration may be warranted for post-concussion assessment in athletes with migraine headaches.

### Summary Points:

- ✓ Pediatric athletes with a history of migraine headache diagnosis performed worse on the K-D test as compared to matched controls without a history of migraine.
- ✓ The results of this study help to further accentuate the need for individualized baseline testing utilizing multifaceted assessment strategies, especially in individuals with premorbid migraine history.



Brain Injury. 2018.

## The Effect of Linguistic Background on Rapid Number Naming: Implications for Native Versus Non-Native English Speakers on Sideline-Focused Concussion Assessments

Rizzo JR, Hudson TE, Amorapanth PX, Dai W, Birkemeier J, Pasculli R, Conti K, Feinberg C, Verstraete J, Dempsey K, Selesnick I, Balcer LJ, Galetta SL, Rucker JC.

**Objective:** To determine if native English speakers (NES) perform differently compared to non-native English speakers (NNES) on a sideline-focused rapid number naming task. A secondary aim was to characterize objective differences in eye movement behaviour between cohorts. **Background:** The King-Devick (KD) test is a rapid number-naming task in which numbers are read from left-to-right.

This performance measure adds vision-based assessment to sideline concussion testing. Reading strategies differ by language. Concussion may also impact language and attention. Both factors may affect test performance. **Methods:** Twenty-seven healthy NNES and healthy NES performed a computerized KD test under high-resolution video-oculography. NNES also performed a Bilingual Dominance Scale (BDS) questionnaire to weight linguistic preferences (i.e., reliance on non-English language(s)). **Results:** Inter-saccadic intervals were significantly longer in NNES ( $346.3 \pm 78.3$  ms vs.  $286.1 \pm 49.7$  ms,  $p = 0.001$ ), as were KD test times ( $54.4 \pm 15.1$  s vs.  $43.8 \pm 8.6$  s,  $p = 0.002$ ). Higher BDS scores, reflecting higher native language dominance, were associated with longer inter-saccadic intervals in NNES. **Conclusion:** These findings have direct implications for the assessment of athlete performance on vision-based and other verbal sideline concussion tests; these results are particularly important given the international scope of sport. Pre-season baseline scores are essential to evaluation in the event of concussion, and performance of sideline tests in the athlete's native language should be considered to optimize both baseline and post-injury test accuracy.

### Summary Points:

- ✓ Inter-saccadic intervals and K-D test times were longer in non-native English speakers.
- ✓ Pre-season baseline scores are essential to evaluation in the event of concussion, and performance of sideline tests in the athlete's native language should be considered to optimize both baseline and post-injury test accuracy.



Journal of Science and Medicine in Sport. 2018.

## The King-Devick test is not sensitive to self-reported history of concussion but is affected by English language skill

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**Objectives:** Head injuries, including concussion, are a concern in many sports. Current validated concussion assessment protocols such as the King-Devick (K-D) test, could be included. This research explores the role of the K-D test in snow sport concussion research. **Design:** Experienced snow sport participants were recruited through a western Canadian resort ( $n = 75$ ). **Methods:** Participants completed a questionnaire that included their history of prior serious head impacts and were assessed via the computer-based K-D test in English. **Results:** Of the 75 participants, 23 (69%) reported at least one previous serious head impact. English was the not primary language for seven participants. Independent sample t-tests revealed: significant differences in the K-D average saccade scores for those who had broken their helmets, with or without a serious head injury ( $x = 171.23$ ,  $SD = 12.9$ ) and those who had not broken a helmet ( $x = 186.61$ ,  $SD = 20.18$ ;  $t(70) = -2.53$ ,  $p = .014$ , two tailed) and significant differences in the K-D time for those whose native language is English ( $x = 47.9$ ,  $SD = 6.3$ ) and those where English was not their first language ( $x = 53.3$ ,  $SD = 7.4$ ;  $t(73) = .48$ ,  $p = .04$ ), but no significant difference for their saccade velocities: English ( $x = 183.64$ ,  $SD = 20.0$ ) versus those where English is a second or third language ( $x = 188.44$ ,  $SD = 20.1$ ;  $t(70) = -.56$ ,  $p = .576$ ). **Conclusions:** For subjects whose first language is not English, such as in many snow sport resorts, the K-D test may need to be conducted in a person's native language to provide a valid assessment based upon the time to complete the task.

### Summary Points:

- ✓ While this research did not show that the K-D test was sensitive to a self-reported history of head impacts in snow sports participants, the results highlighted that language skills, and potentially reading ability, of participants needs to be considered when relying upon the time for completion of a reading test to assess neurological responses following a head impact.



Journal of Neurological Sciences. 2019.

### **King-Devick Computerized Neurocognitive Test Scores in Professional Football Players with Learning and Attentional Disabilities**

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**Objective:** This study examined outcomes from the King Devick (K-D) in athletes with Learning Disabilities (LD) and attention disorders (ADHD). **Methods:** A total of 574 professional football players from the Canadian Football League (CFL) completed baseline evaluations with computerized neurocognitive testing (CNT) prior to the 2016 competitive season. Player age, education, history of concussion, LD, and ADHD were analyzed for K-D and Immediate Post Concussion Assessment and Cognitive Testing (ImPACT) performance. A series of analyses of co-variance (ANCOVA's) were used to compare participants with a history of LD and ADHD with history of concussion as a co-variate. **Results:** Approximately 5% of participants reported a diagnosed history of LD and 13% with ADHD. Performance on the K-D test was not significantly correlated with age, education, or history of concussion but was significantly correlated with history of LD and ADHD. Participants with LD performed approximately 6.9 seconds slower on the K-D test ( $t[563] = 4.70$ ,  $p = 0.0003$ ) and participants with ADHD were approximately 2 seconds slower ( $t[572] = 2.04$ ,  $p = 0.04$ ). **Conclusions:** Results indicated that players with a history of diagnosed LD and ADHD performed slower on the K-D test in comparison to athletes with no history of diagnoses. The results of this study underscore the importance of recognizing individualized outcomes when using the K-D.

### Summary Points:

- ✓ Performance on the K-D test was significantly correlated with history of LD and ADHD.
- ✓ Participants with a history of LD performed approximately 6.9 seconds slower on the K-D test, a result consistent with findings of slower K-D scores in LD samples.
- ✓ Players with a history of ADHD presented with statistically significant slower performance (1.9 seconds slower) when compared to the non-ADHD group.
- ✓ There was no significant effect for history of concussion on K-D baseline score.
- ✓ The K-D Test was significantly correlated with Visual Motor Processing, Visual Memory, and Reaction Time, however R-squared values were low suggesting little overlap between the cognitive abilities suggesting that the K-D Test adds unique information to the clinical outcomes associated with concussion.

Journal of Sports Medicine and Therapy

J Sports Med Ther. 2017; 2: 009-019.

### **Parents Take-On Concussion: Advances in Sideline Research and Culture in Youth Sports**

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Identifying concussion and initiating removal from play is challenging for even the most diligent youth sports organizations. Empowering parents to implement removal from play protocols and sideline testing may be the most practical plan at community levels to protect young athletes. We developed paradigms for community-based youth sports teams that incorporated both standard concussion protocols and research investigations. The research studies were designed to determine how sideline tests of vision, cognition and balance augment the capacity for parents and other responsible adults to identify youth athletes with concussion in ice hockey, football, lacrosse and cheerleading. Research-based sideline tests were performed at pre-season baseline sessions and during the season at the time of injury or as soon as symptoms were recognized by trained volunteer parent team testers. The combination of standard concussion protocols and research studies were performed for 510 athletes, aged 5-17 years, over 2.5 years through 5 athletic seasons. To implement the protocols and studies, approximately 80 student volunteers and parents were educated and trained on early concussion recognition and on baseline and sideline test administration. Over 80% of parent-identified head injuries were physician-confirmed concussions. Of the sideline tests performed, over two-thirds were administered within 24 hours of injury; the rest were performed within an average of 2.6 days post-injury since some athletes had delayed development of symptoms. Removal from play guidelines and standard concussion evaluation protocols were maintained in the context of the sideline testing research investigations. Based on this observational study, parents of youth athletes can be successfully empowered to perform rapid sideline tests in the context of existing concussion protocols. Implementation of objective testing may improve concussion identification and shift the culture of advocacy and responsibility towards parent groups to promote safety of young athletes. Ongoing investigations will further examine the impact of these programs on concussion management in youth sports.

### Summary Points:

- ✓ The Advanced Concussion Recognition (ACR) Initiative was designed and conducted to be integrated into the “real world” environment of youth sports organizations, which necessarily incorporate parents, coaches and student volunteers. Research-based baseline and sideline tests included rapid number naming (King-Devick test), the Symptom Evaluation from the Sport Concussion Assessment Tool, 3rd Edition (SCAT3, for athletes 13 years and older) or Child-SCAT3 (for children 5-12 years old) and the timed tandem gait test.
- ✓ Parents, coaches and athletes were encouraged, as part of the ACR initiative and by the standard concussion protocols, to identify any head injury and to initiate testing even if the injury was minor.
- ✓ 83% (n=62) of 75 reported head injuries identified by parents were physician-confirmed concussions.
- ✓ The Advanced Concussion Recognition (ACR) Initiative educates parents to recognize the signs and symptoms of concussion, provides guidelines to remove an athlete from play, trains them to perform simple concussion screening tests, and institutes the basic first aid of concussion (i.e. rest) until an athlete can be evaluated by a healthcare provider.
- ✓ Parents are capable of learning and recognizing the signs and symptoms of concussion when provided with effective educational materials and instructions for implementing this knowledge.
- ✓ Parents can be feasibly empowered to perform standardized, age-appropriate rapid sideline tests of vision, balance, cognition and symptoms.



The International Journal of Sports Physical Therapy; 2017; 12(4):581.

### **Relationships Among Common Visual and Vestibular Tests in Healthy Recreational Athletes**

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**Background:** Disruption of the visual and vestibular systems is commonly observed following concussion. Researchers have explored the utility of screening tools to identify deficits in these systems in concussed patients, but it is unclear if these tests are measuring similar or distinct phenomena. **Purpose:** To determine the relationships between common vestibular tests including the King-Devick (K-D) test, Sensory Organization Test (SOT), Head Shake-Sensory Organization Test (HS-SOT), and Dynamic Visual Acuity (DVA) test, when administered contiguously, to healthy recreational athletes aged 14 to 24 years. **Study Design:** This study used a

prospective design to evaluate relationships between the K-D, SOT, HSSOT, and DVA tests in 60 healthy individuals. **Methods:** Sixty participants (30 males, 30 females; mean age,  $19.9 \pm 3.74$  years) completed the four tests in a single testing session. **Results:** Results did not support a relationship between any pair of the K-D, SOT, HS-SOT, and DVA tests. Pearson correlations between tests were poor, ranging from 0.14 to 0.20. As expected the relationship between condition 2 of the SOT and HS-SOT fixed was strong ( $ICC=0.81$ ) as well as condition 5 of the SOT with HS-SOT sway ( $ICC=0.78$ ). The test-retest reliability of all 4 tests was evaluated to ensure the relationships of the 4 tests were consistent between test trials and reliability was excellent with intraclass correlations ranging from 0.79 to 0.97. **Conclusions:** The lack of relationships in these tests is clinically important because it suggests that the tests evaluate different aspects of visual and vestibular function. Further, these results suggest that a comprehensive assessment of visual and vestibular deficits following concussion may require a multifaceted approach.

### Summary Points:

- ✓ An easily administered screening tool, the King Devick (K-D) test, assesses both the visual and vestibular systems.
- ✓ K-D Test also incorporates the cognitive domain because it identifies impairment of eye movements, attention, language, and other symptoms that are associated with suboptimal brain function.
- ✓ The results of the current study are clinically important because knowing that there are no relationships between the K-D, SOT, HS-SOT, and DVA tests may encourage healthcare professionals to appreciate the complexity of impairments to visual/vestibular function.
- ✓ Each of these tests seems to be measuring a specific, and seemingly independent, aspect of the visual or vestibular system - the K-D test assesses saccadic accuracy and attention and identifies oculomotor deficits.



### **Correlating the King-Devick Test with Vestibular/Ocular Motor Screening in Adolescent Patients with Concussion: A Pilot Study**

Russell-Giller S, Toto D, Heitzman M, Naematullah M, Shumko J  
Sports Health 2018

**Background:** The King-Devick (K-D) test is a rapid number-naming task that has been well validated as a sensitive sideline performance measure for concussion detection. Patients with concussion take significantly longer to complete the K-D test than healthy controls. Previous research suggests that ocular motor deficits, specifically saccadic abnormalities, may be an underlying factor for the

prolonged time. However, these findings have not been studied at length.

**Hypothesis:** K-D testing time of concussed adolescents at the initial clinical concussion visit will positively correlate with vestibular/ocular motor screening (VOMS) total scores.

**Study Design:** Case series.

**Level of Evidence:** Level 3.

**Methods:** A total of 71 patient charts were retrospectively analyzed between October 1, 2016, and January 31, 2017. Included charts consisted of patients between the ages of 10 and 18 years with a diagnosis of concussion and who had completed K-D testing and VOMS assessment at the initial physician visit. Univariate correlation between K-D testing time and the 7 VOMS items was assessed using Pearson correlation coefficients.

**Results:** K-D testing time strongly correlated with all 7 VOMS items ( $r(69) = 0.325-0.585$ ,  $P < 0.01$ ). In a linear regression model that accounted for each VOMS item, the convergence (near point) item and the visual motion sensitivity item significantly predicted K-D testing time ( $\beta = 0.387$ ,  $t(63) = 2.81$ ,  $P < 0.01$  and  $\beta = 0.375$ ,  $t(63) = 2.35$ ,  $P = 0.02$ , respectively). Additionally, 37.5% of the 24 patients with worsening symptoms after K-D testing freely reported increased visual problems.

**Conclusion:** Our study suggests that prolonged K-D testing times in adolescents with concussion may be related to subtypes of vestibular/ocular motor impairment that extend beyond saccadic abnormalities.

**Clinical Relevance:** Poor K-D testing performance of adolescents with concussion may indicate a range of vestibular/ocular motor deficits that need to be further identified and addressed to maximize recovery.

### Summary Points:

- ✓ K-D Test scores showed high correlation with vestibular-ocular performance.
- ✓ Near point of convergence and visual motion sensitivity significantly predicted K-D Test scores.

- ✓ K-D Test may be indicative of a range of vestibular and oculomotor deficits.
- ✓ Baseline measures are important in cases where individuals have a pre-existing vision condition that may affect test scores.
- ✓ As expected, the vertical and horizontal saccades significantly correlated with prolonged K-D time.
- ✓ Results suggest that prolonged K-D testing times may be related to vestibular/ocular motor impairment beyond saccadic abnormalities alone.



Clin Sports Med. 36(2017) 717-739.

### **Sport Concussion and the Female Athlete**

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Sport concussion (SC) has emerged as a major health concern in the medical community and general public owing to increased research and media attention, which has primarily focused on male athletes. Female athletes have an equal, if not increased, susceptibility to SC. An

ever-growing body of research continues to compare male and female athletes in terms of SC before and after an injury. Clinicians must be cognizant of this literature to make evidence-based clinical decision when providing care to female athletes and discern between dated and/or unsupported claims in terms of SC.

*More recently, clinical measures based on visual tasks have been introduced as viable sideline measures of SC. Most notably, the King-Devick (K-D) test has gained attention as a promising sideline measure of SC. The K-D test is a rapid visual screening tool that assesses the speed and accuracy of an athlete reading numbers from left to right in increasingly complex patterns provided on alternative cards, which requires the use of saccades and concentration to complete. Increasing time to completion on the K-D test is purported to reflect impaired eye movements, which is suggestive of suboptimal brain function. The K-D test has been demonstrated to have strong evidence of test–retest reliability, sensitivity, and specificity with variable test–retest intervals across a wide range of age, sport, and nonsport groups. Additionally, preliminary evidence suggests sex does not seem to influence K-D test performance. Thus far, the evidence remains promising for the K-D test as a sideline measure of SC.*



J Am Osteopath Assoc. 2018.

### **Concussion Evaluation and Management: An Osteopathic Perspective**

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*New York Institute of Technology (NYIT) College of Osteopathic Medicine; the NYIT Center for Sports Medicine; Department of Occupational Therapy at the NYIT School of Health Professions*

Concussions have been increasingly reported over the past decade, but the reported incidence likely minimizes the actual numbers of people affected. Associated symptoms include emotional, somatic, and cognitive complaints, which may be prolonged in patients with certain risk factors. Neurologic examination is necessary to exclude upper motor neuron lesions and thus the need for brain imaging. Cervical conditions are often found concurrently with head injury and displays a similar presentation to concussions. Therefore, determining symptom origin can be problematic. Neuropsychological, oculomotor, and balance evaluations expose specific deficits that can be successfully managed with rehabilitation. Osteopathic assessment of the cranium, spine, sacrum, and thorax for somatic dysfunctions allows for prudent interventions. Patients involved in sports may begin an established graduated return-to-play protocol once cleared by their physician. Concurrently, a parallel return-to-learn program, with applicable academic accommodations, is recommended.

### **Summary Points:**

- ✓ Saccadic dysfunction is prevalent in patients with concussion and correlates with a poorer recovery.
- ✓ King-Devick testing offers a validated and objective 1- to 2-minute assessment of saccades, attention, and language.

- ✓ Persistent symptoms may include visual disturbances. Rehabilitation including visual, vestibular and cognitive therapy has demonstrated effectiveness in several postconcussion conditions.



Clinical Journal of Sports Medicine. 2019;29(2):87-100

## **American Medical Society for Sports Medicine position statement on concussion in sport**

Harmon KG, Clugston JR, Dec K, Hainline B, Herring S, Kane SF, Kontos AP, Leddy JJ, McCrea M, Poddar SK, Putukian M, Wilson JC, Roberts WO.

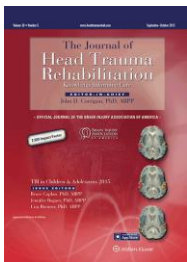
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Sport-related concussion (SRC) is a common injury in recreational and organised sport. Over the past 30 years, there has been significant progress in our scientific understanding of SRC, which in turn has driven the development of clinical guidelines for diagnosis, assessment and management of SRC. In addition to a growing need for knowledgeable healthcare professionals to provide evidence-based care for athletes with SRC, media attention and legislation have created awareness and, in some cases, fear about many issues and unknowns surrounding SRC. The American Medical Society for Sports Medicine (AMSSM) formed a writing group to review the existing literature on SRC, update its previous position statement, and to address current evidence and knowledge gaps regarding SRC. The absence of definitive outcomes-based data is challenging and requires relying on the best available evidence integrated with clinical experience and patient values. This statement reviews the definition, pathophysiology and epidemiology of SRC, the diagnosis and management of both acute and persistent concussion symptoms, the short-term and long-term risks of SRC and repetitive head impact exposure, SRC prevention strategies, and potential future directions for SRC research. The AMSSM is committed to best clinical practices, evidence-based research and educational initiatives that positively impact the health and safety of athletes.

### **Summary Points:**

- ✓ King-Devick Test is included as an emerging sideline concussion evaluation tool.
- ✓ Articles (n=9) reviewed in Table 3 report data from a variety of athlete types and levels, sensitivity ranging from 60-100% and specificity ranging from 39-100%, reliability ranging from 0.90- 0.95.



J Head Trauma Rehab. 2018;33(5): 354-361.

## **Options for Evaluating and Tracking Pediatric Concussion**

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It is estimated that 45 million persons between the ages of 5 and 19 years participate in some form of athletic activity.<sup>1</sup> It is further estimated that 5% to 10% of sports participants in this age range will suffer a sports-related concussion, leading to an emergency department visit. Presumptively, a

significant number of injured youth do not go to emergency rooms and deal with their symptoms at home. Due to the dramatic increase in awareness and concern regarding sports concussions among athletes of all ages, there has been a need for more valid and reliable methods for determining whether a concussion has occurred and, if so, how long the effects persist. Traditionally, concussions were evaluated “clinically,” that is, by observation and interview of the concussed individual by witnesses and/or athletic trainers. Except in cases involving prolonged periods of unconsciousness, physicians were rarely involved. Formal evaluations by neuropsychologists were generally limited to these more severe cases, and rarely addressed the issue of a mild concussion with minimal or no loss of consciousness. As our understanding



of concussions evolved, due in part to the introduction of advanced neuroimaging techniques, it became clear that many individuals who had suffered apparently minor head blows had in fact experienced subtle changes in brain functionality that provided a physiological basis for many of their immediate and short-term postconcussive signs and symptoms. The need for a more efficient way of detecting and tracking concussions over time was obvious, and not surprisingly a number of developers have introduced devices or computer software designed to address these key issues. The present article describes some of the principal providers of concussion detection and tracking technology available without attempting to critique or recommend one system over another. Suffice it to say, every attempt has been made to select methodologies, which either have a “track record” in the field or show promise for becoming more prominent due to innovative approaches and data gathering.

#### **KING-DEVICK TEST IN ASSOCIATION WITH MAYO CLINIC**

*The King-Devick Test (K-DT) was one of the first concussion assessment systems to focus primarily upon eye movements to diagnose and track sports-related concussions. It was initially developed by optometrists Alan King and Stephen Devick as a diagnostic tool for identifying reading difficulties. Subsequently, the methodology was applied to identifying concussions and has resulted in promising research. The task presented in the King-Devick Test in Association with Mayo Clinic (K-DT MC) is relatively simple: the examinee is asked to read individual letters displayed either on paper or on a handheld tablet. The examinee is instructed to proceed as rapidly as possible, to avoid errors (commission or omission), and to refrain from touching the screen. The K-DT MC does not employ norms in the traditional sense of that term. A subject's performance is compared with his or her previously established baseline. Baseline performance is defined as the faster of 2 error-free administrations. The examiner records errors (including self-corrections) and time to complete each task. If the test is administered using a tablet (iPad or Android) and there is a Wi-Fi connection, results can be recorded and transmitted to a designated location. Failure on a postinjury administration is defined as an increase in the time score or number of errors will result in a “worse than baseline” performance. The computer system does make this determination but only states that the performance difference either was or was not within expected parameters. If the subject performs faster than baseline, then this latest performance becomes the new baseline. One of the advantages of the system is its simplicity and portability.*



### **Review of Assessment Scales for Diagnosing and Monitoring Sports-related Concussion**

Dessy AM, Yuk FJ, Maniya AY, Gometz A, Rasouli JJ, Lovell MR, Choudhri TF  
Cureus. 2017 Dec 7;9(12):e1922

Sports-related concussion has emerged as a public health crisis due to increased diagnosis of the condition and increased participation in organized and recreational athletics worldwide. Under-recognition of concussions can lead to premature clearance for athletic participation, leaving athletes vulnerable to repeat injury and subsequent short- and long-term complications. There is overwhelming evidence that assessment and management of sports-related concussions should involve a multifaceted approach. A number of assessment criteria have been developed for this purpose. It is important to understand the available and emerging diagnostic testing modalities for sports-related concussions. The most commonly used tools for evaluating individuals with concussion are the Post-Concussion Symptom Scale (PCSS), Standard Assessment of Concussion (SAC), Standard Concussion Assessment Tool (SCAT3), and the most recognized computerized neurocognitive test, the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT). The strengths and limitations of each of these tools, and the Concussion Resolution Index (CRI), CogSport, and King-Devick tests were evaluated. Based on the data, it appears that the most sensitive and specific of these is the ImPACT test. Additionally, the King-Devick test is an effective adjunct due to its ability to test eye movements and brainstem function.

#### **Summary Points:**

- ✓ This study identified the benefits of the K-D Test that are unique to concussion assessment tools.
- ✓ The K-D Test is easy to administer, tests eye movement and brainstem functions that other tests do not and is able to identify events in athletes without symptoms of concussion (unrecognized concussions).
- ✓ The K-D Test is an effective addition to the concussion screening protocol.



Seminars in Neurology. 2015; 35:599-606.

## The Concussion Toolbox: The Role of Vision in the Assessment of Concussion

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Concussion may lead to subtle changes in brain function, and tests involving the visual system probe higher cortical functioning and increase our sensitivity in detecting these changes. Concussions are acutely and sometimes more persistently associated with abnormalities in balance, cognition, and vision. The visual system involves roughly half of the brain's circuits, including many regions susceptible to head impacts. After a concussion, the neuro-ophthalmologic exam commonly detects abnormalities in convergence, accommodation, the vestibulo-ocular reflex, ocular muscle balance, saccades, and pursuit. The King-Devick (K-D) test is a visual performance measure that may increase the sensitivity of detecting concussions on the sideline when used in combination with tests of cognition and balance that are part of the Sports Concussion Assessment Tool (3rd ed.; SCAT3). Portable eye movement trackers and pupillometry may in the future improve our neuro-ophthalmic assessment after concussions. Combining visual tasks with neuroimaging and neurophysiology has allowed subtle changes to be detected, may refine our ability to make appropriate return-to-play decisions, and could potentially determine susceptibility to long-term sequelae of concussion.

### Summary Points:

- ✓ Given that about half the brain's circuits are involved in vision, it is not surprising that concussions often involve injuries to visual pathways and post-concussive visual complaints are common.
- ✓ The K-D test is a performance measure that allows an assessment of eye movements in an easy to administer, objective manner.
- ✓ Rapid number naming requires saccades, attention, and language, as well as other areas involved in reading, and the K-D test thereby evaluates function of the brainstem, cerebellum, and cerebral cortex.
- ✓ The K-D test has been studied in MMA fighters, boxers, collegiate athletes, professional hockey players, and rugby players and it has been found that there is a 5- to 7-second increase in scores immediately post-concussion compared with baseline.
- ✓ The most commonly used sideline tests such as the SAC and BESS do not assess eye movements. The K-D test incorporates eye movements and when used in combination with the SAC and BESS increases the sensitivity of detecting concussions.
- ✓ The K-D test has the greatest capacity to distinguish those who sustained concussion versus controls when compared with a timed tandem-gait test and the SAC.
- ✓ Tests involving the visual system can probe higher cognitive functioning and can increase our ability to detect subtle changes associated with head impacts.



Neurosurg Focus. 2016; 40(4):E7.

## Clinical Evaluation of Concussion: the Evolving Role of Oculomotor Assessments

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Sports-related concussion is a change in brain function following a direct or an indirect force to the head, identified in awake individuals and accounting for a considerable proportion of mild traumatic brain injury. Although the neurological signs and symptoms of concussion can be subtle and transient, there can be persistent sequelae, such as impaired attention and balance that make affected patients particularly vulnerable to further injury. Currently, there is no accepted definition or diagnostic criteria for concussion, and there is no single assessment that is accepted as capable of identifying all patients with concussion. In this paper, the authors review the available screening tools for concussion, with particular

emphasis on the role of visual function testing. In particular, they discuss the oculomotor assessment tools that are being investigated in the setting of concussion screening.

### Summary Points:

- ✓ KDT is an assessment of visual function, but it also assesses the integrity of attention
- ✓ Healthy athletes have been shown to improve on the KDT with repeated testing and with exercise
- ✓ Thus, any decline in performance (that is, an increase in score time) compared with baseline testing suggests concussion
- ✓ KDT is ideal in that it takes less than 1–2 minutes to complete and can be administered by nonmedical personnel such as parents or coaches
- ✓ Current evidence suggests that the KDT can serve as a complementary test to increase the sensitivity
- ✓ Ideally, a sideline screening assessment should also be standardized, cost-effective, and able to be administered by nonmedical personnel, such that it is practical in youth and high-school athletics, as well as collegiate and professional sports.



J Neuro-ophthalmol. 2015 Mar;35(1):73-81.

### **Diagnostic tests for concussion: is vision part of the puzzle?**

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**Background:** Concussion, particularly in relation to sports and combat activities, is increasingly recognized as a potential cause of both short- and long-term neurologic sequelae. This review will focus on the neuro-ophthalmologic findings associated with concussion, the current tests for concussion, and the potential for visual performance measures to improve our detection and assessment of concussions. **Evidence Acquisition:** A PubMed search using the specific key words "concussion," "mild traumatic brain injury," "neuro-ophthalmological findings," and "diagnostic and management tests" was performed. An emphasis was placed on articles published during the past 5 years, but additional articles referenced within recent publications were obtained. **Results:** Concussion is frequently associated with abnormalities of saccades, pursuit eye movements, convergence, accommodation, and the vestibular-ocular reflex. Current sideline testing for athletes includes the Sports Concussion Assessment Tool, Third Edition (SCAT3) incorporates cognitive and balance testing. The King-Devick (K-D) test is a rapid visual performance measures that can be used on sidelines by nonmedical personnel, including parents of youth athletes. The K-D test complements components of the SCAT3 and improves the detection of concussions. Other vision-based tools for diagnosing and for managing concussion include eye movement tracking devices, pupillary assessment, computerized testing, imaging modalities, and electrophysiologic testing. Many of the imaging modalities and electrophysiological studies have been combined with vision-based tests. **Conclusions:** Concussion is associated with many neuro-ophthalmologic signs and symptoms. Visual performance measures enhance the detection and management of concussion, and future studies are under way to further incorporate vision-based testing into sideline diagnosis and long-term clinical assessments.

### Summary Points:

- ✓ Patients with post-concussion syndrome demonstrate saccadic dysfunction.
- ✓ 60% of mTBI patients have abnormal pursuits or smooth eye movements.
- ✓ Studies of MMA fighters, boxers, collegiate athletes, professional hockey players, and rugby players score an average 5 to 7 seconds longer on the K-D test of rapid number naming immediately after a concussive event compared to their baseline scores (pre-season or pre-fight scores).
- ✓ Adding the K-D test to concussion screening, along with BESS and SAC, detected 100% of athletes with concussions, whereas BESS and SAC alone failed to flag 10% of the concussed athletes.

Traumatic brain injury (TBI) is a major cause of morbidity and mortality. Concussion, a form of mild TBI, might be associated with long-term neurological symptoms. The effects of TBI and concussion are not restricted to cognition and balance. TBI can also affect multiple aspects of vision; mild TBI frequently leads to disruptions in visual functioning, while moderate or severe TBI often causes structural lesions. In patients with mild TBI, there might be abnormalities in saccades, pursuit, convergence, accommodation, and vestibulo-ocular reflex. Moderate and severe TBI might additionally lead to ocular motor palsies, optic neuropathies, and orbital pathologies. Vision-based testing is vital in the management of all forms of TBI and provides a sensitive approach for sideline or post-injury concussion screening. One sideline test, the King-Devick test, uses rapid number naming and has been tested in multiple athlete cohorts.

### Summary Points:

- ✓ Since areas of the brain which control eye movements are vulnerable to trauma, mild TBI or concussions often lead to visual symptoms and clinical signs, which need specific evaluation.
- ✓ Common consequences of mild TBI include deficits in eye movements, executive function, visual attention, and visual memory.
- ✓ The K-D test evaluates eye movements (saccades), attention, and language, and a sensitive measure for concussion screening.



Clin J Sport Med 2017; 0; 1-7

### **Concussion in Ice Hockey: Current Gaps and Future Directions in an Objective Diagnosis**

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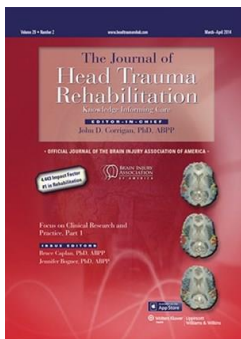
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**Objective:** This review provides an update on sport-related concussion (SRC) in ice hockey and makes a case for changes in clinical concussion evaluation. Standard practice should require that concussions be objectively diagnosed and provide quantitative measures of the concussion injury that will serve as a platform for future evidence-based treatment. **Methods:** The literature was surveyed to address several concussion-related topics: research in ice hockey-related head trauma, current subjective diagnosis, promising components of an objective diagnosis, and current and potential treatments. **Main Results:** Sport-related head trauma has marked physiologic, pathologic, and psychological consequences for athletes. Although animal models have been used to simulate head trauma for pharmacologic testing, the current diagnosis and subsequent treatment in athletes still rely on an athlete's motivation to report or deny symptoms. Bias-free, objective diagnostic measures are needed to guide quantification of concussion severity and assessment of treatment effects. Most of the knowledge and management guidelines of concussion in ice hockey are generalizable to other contact sports. **Conclusions:** There is a need for an objective diagnosis of SRC that will quantify severity, establish a prognosis, and provide effective evidence-based treatment. Potential methods to improve concussion diagnosis by health care providers include a standardized concussion survey, the King-Devick test, a quantified electroencephalogram and blood analysis for brain cell-specific biomarkers.

### Summary Points:



- ✓ The King-Devick (K-D) test, a time-based measure of saccades and other eye movements, detects concussion with high levels of sensitivity (86%) and specificity (90%) at rink-side or point of care
- ✓ Recently, 141 youth hockey players underwent KD testing before season, after season and immediately after suspected concussion. Testing was also performed in a subgroup of nonconcussed athletes immediately before and after games to determine the impact of fatigue on KD scores. Twenty athletes sustained a concussion, and all 20 had immediate postconcussion KD testing times, which deviated more than 5 seconds from baseline (average 7.3 s) and all but 2 had worse postseason scores (46.4 seconds vs 52.4 seconds,  $P = 0.05$ ). In contrast, 51 nonconcussed players assessed before and after a game revealed no significant time change as a result of fatigue. This study indicated that the KD test accurately identified realtime, symptomatic concussion in youth athletes.
- ✓ Players will benefit from having provided preseason and postseason KD testing, as sports medicine providers will have a real-time objective evaluation at point of care to support the diagnosis of concussion.
- ✓ To advance the science of concussion, objective measures to diagnose concussion and document the resolution of brain-related changes must be developed. Variations from baseline in 3 objective measures—the KD test, the QEEG, and neurobiomarkers—may confirm concussion and measure of severity of the brain injury. These potential objective measures will enable promising therapeutic options to be studied for efficacy in concussion management.



J Head Trauma Rehabil. 2015. Doi: 10.1097/HTR.0000000000000174

## Oculomotor-Based Vision Assessment in Mild Traumatic Brain Injury: A Systematic Review

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**Objective:** The purpose of this article is to synthesize and appraise the evidence regarding the use of oculomotor based vision assessment to identify and monitor recovery from mild traumatic brain injury (mTBI). Specific objectives are to (1) identify changes in oculomotor-based vision following mTBI; (2) distinguish methods of assessment; (3) appraise the level and quality of evidence; and, if warranted, (4) determine clinical recommendations for assessment. **Methods:** A systematic review was undertaken to identify and appraise relevant literature. A search was conducted of 7 databases of peer-reviewed literature from January 1990 to January 2015. Articles were included if study populations were clearly identified as having mTBI and used an assessment of oculomotor-based vision. Articles with pooled data (eg, mTBI and stroke), addressing afferent visual function (eg, visual field deficits) or using single case designs, were excluded. **Results:** Twenty articles were selected for inclusion. Exploratory findings suggest that measurements of saccades, smooth pursuit, and vergence are useful in detecting changes associated with mTBI. Assessment methods included eye tracker protocols, optometric assessment, and the King-Devick test. **Conclusion:** The strength of this evidence is not yet sufficient to warrant clinical recommendations. Research using rigorous methods is required to develop reliable, valid, and clinically useful assessment protocols. Key words: accommodation, concussion, eye movements, King-Devick test, mild traumatic brain injury, oculomotor, pursuit, saccades, systematic review, vergence, vision.

### Summary Points:

- ✓ Changes in saccadic eye movements are reported in individuals with mTBI
- ✓ Saccadic eye movements are the most investigated eye movement in sports-related concussion literature where the need for a sideline tool to objectively detect impairment due to mTBI has been recognized.
- ✓ Studies used the King-Devick test to examine the effect of mTBI on saccadic eye movements.

- ✓ The King-Devick test requires very minimal setup or administrator training and is typically administered in less than 2 minutes.
- ✓ A high degree of test-retest reliability using inter-class correlation is reported with the King-Devick test in relation to investigating head trauma.
- ✓ The King-Devick test measures saccadic reaction time which has been shown to be slowed following mTBI (as compared with controls) in eye tracking studies.
- ✓ Results from all sports-related studies reviewed indicate that performance on the King-Devick test was significantly slowed following concussion compared with preinjury baseline performance.
- ✓ Test scores improved to baseline levels (preconcussion) within 2 to 3 weeks postinjury.
- ✓ Multiple oculomotor and cognitive skills are used to complete the King-Devick test. Abnormalities in test performance are not specific to saccades and may be reflective of impairment in other oculomotor (eg, vergence, accommodation) and cognitive functions (eg, attention).



J Can Chiropr Assoc. 2016; 60(4)

### The utility of the King-Devick test as a sideline assessment tool for sport-related concussions: a narrative review

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<sup>1</sup> Canadian Memorial Chiropractic College

**Objective:** The objective of this paper is to review existing literature surrounding the utility of the King-Devick test which is a commonly used sideline assessment tool for sport-related concussions. **Methods:** A review of the literature was performed using MEDLINE, CINAHL, and SportDiscus databases. The search was performed from the beginning of the record through November 16th, 2015. **Results:** This search strategy yielded 27 articles from aforementioned databases. Further searching in The Cochrane Library with King-Devick AND Concuss\* search terms yielded one additional article, summing a total of 28 articles. After removal of duplicates and implementation of the inclusion/exclusion criteria, 8 articles for extensively reviewed. **Conclusion:** This narrative review suggests that the King-Devick test is an efficient sideline assessment tool for sport-related concussions. However, we recommend that the King-Devick should be used as a sideline screening tool, not a concussion diagnosis tool at this time. A proper baseline time including multiple tests may be recommended to negate the learning affect and to have a reliable baseline in which to measure from for future reference. A three second difference appears appropriate to identify the possibility of concussion and to remove an athlete from play. At this time, the athlete should be monitored and further evaluated as symptoms are sometimes delayed. We suggest that further research may be useful to better determine the efficacy of the K-D test in detecting concussions across a broader range of athletes and sports. We also suggest further research may investigate the K-D test a potential return-to-play tool for clinicians and medical personnel.

### Summary Points:

- ✓ This review supports the use of the King-Devick test as an efficient sideline assessment tool for sport-related concussions
- ✓ Successful identification of concussions and appropriate subsequent management will lead to a reduced risk of a secondary concussion and long-term neurological complications



J Neurol Sci. 2016. 361:79-86. <http://dx.doi.org/10.1016/j.jns.2015.12.010>

### Review article: Ocular motor assessment in concussion: Current status and future directions

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Mild head injury such as concussions and subconcussive repetitive impact may lead to subtle changes in brain function and it is imperative to find sensitive and reliable tests to detect such changes. Tests involving the visual system, in particular eye movements, can incorporate higher cortical functioning and involve diffuse pathways in the brain, including many areas susceptible to head impact. With concussions, the clinical neuro-ophthalmic exam is important for detecting abnormalities in vergence, saccades, pursuit, and visual fixation. On the sidelines, the King–Devick test has been used as a visual performance measure that incorporates eye movements and increases the sensitivity in detecting possible concussions in conjunction with standard sideline tests of cognition, symptom checklists, and balance. Much promise lies in the eye movement laboratory to quantitate changes in saccades and pursuit with concussions using video-oculography. A combination of eye movement tasks coupled with neuroimaging techniques and other objective biomarkers may lead to a better understanding of the anatomical and physiological consequences of concussion and to better understand the natural history of this condition.

### Summary Points:

- ✓ The K-D test allows a rapid, reliable, and objective assessment that incorporates eye movements.
- ✓ Performing the K–D test involves saccades, attention, and language and thus evaluates diffuse networks in the brain, including the networks for saccade generation in the brainstem, cerebellum, and areas of the cerebral cortex such as the DLPC, frontal eye fields, supplementary motor area, and parietal lobes.
- ✓ Worsening from baseline is consistent with the diagnosis of concussion, since in healthy athletes the scores typically improve with practice and are not adversely affected by physical activity.
- ✓ In a meta-analysis of 15 studies evaluating the ability of the K–D test to detect concussions in a variety of sports including hockey, lacrosse, football, basketball, soccer boxing, and rugby, the K–D test was found to have a sensitivity of 86% and a specificity of 90%.
- ✓ Multiple lines of evidence have emerged to show that this test incorporating eye movements, the K–D test, is sensitive and specific in detecting concussions on the sidelines and complements tests of balance and the SAC as a performance measure.

**Annals of Internal Medicine**  
Established in 1927 by the American College of Physicians

Ann Intern Med. 2014 Feb; 160(3):ITC2-1-1.

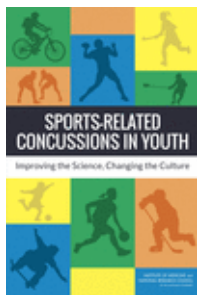
### **In the Clinic: Concussion**

Master CL, Balcer LJ, Collins M

For the oculomotor examination, an additional test that may be used is the **King–Devick test**, which is a tool that rapidly assesses eye movement and can be used in the office or on the sideline to determine impairment in eye movements associated with an acute concussion. This has been found to be potentially useful as a tool to determine removal from play. The 1-minute test involves reading single digits displayed on cards; any slowing of time to complete the test, ideally compared with the athlete's baseline, is suggestive of concussion.

### Summary Points:

- ✓ The K-D Test rapidly assesses eye movements, which can provide insight in concussion recovery and initial sideline testing. Any score below baseline, is considered a red flag for further evaluation for concussion.



Washington DC: National Academies Press 2013.

## **Sports-Related Concussions in Youth: Improving the Science, Changing the Culture**

*US National Research Council, Institute of Medicine. Reports funded by National Institutes of Health.*

The King-Devick test is designed to assess saccadic eye movements, measuring the speed of rapid number naming as well as errors made by the athlete, with the goal of detecting impairments of eye movement, attention, and language as well as impairments in other areas that would be indicative of suboptimal brain function (Galetta et al., 2011a). The King-Devick test includes a demonstration and three test cards with rows of single-digit numbers that are read aloud from left to right. The participant is asked to read the numbers as quickly as possible without making any errors. The administrator records the total time to complete the three cards and the total number of errors made during the test. The results are compared to a personal baseline. The King-Devick test usually takes approximately 2 minutes to complete and can be administered on either an iPad or hardcopy (King-Devick, 2013). **“Such tools as well as balance tests may be used either by trained responders as part of an acute sideline or in-field assessment or by health care providers during subsequent clinical evaluation”**

### Summary Points:

- ✓ The K-D Test is a clinical tool in concussion management that is easy to administer in less than 2 minutes.
- ✓ K-D Test assesses oculomotor ability, rapid number naming, visual attention, and language, which gives insight into neurological pathways controlling these skills, which are often affected by head trauma.
- ✓ K-D Test can be used by trained responders in acute sideline assessment and healthcare providers in clinical evaluation.



Neurosurgery. 2013 Oct; 73(4):N17-8

### **Visual Screening Test for Rapid Sideline Determination of Concussive and Sub-concussive Events**

*Duenas, Matthew J, Hsu, Sarah N, Jandial, Rahul*

In parallel with recognition of concussions as an increasing occurrence in sports the development of tools to help guide decision-making during sporting events has become a priority. Ideally, patients with concussions would be evaluated and cleared by physicians and this remains the medical recommendation. Both National Football League (NFL) and collegiate athletics in the United States have the resources to implement these protective personnel due to the robust financial revenue streams from media contracts. The NFL requires teams to have a neurologist or neurosurgeon on the sidelines. Many collegiate sports have designated trainers that work with athletes throughout the season. Conversely, amateur leagues and most importantly youth sports lack the presence of clinicians or trainers with the ability to detect and intervene on a player's behalf. This underscores the ground level need and the opportunity for a basic yet highly predictive sideline test that can be performed by laypersons during a game to determine concussive as well as sub-concussive events.

Most researchers believe that the rate of concussion injury in sport is underreported due to the lack of a test to help establish the existence of a concussion. King et al, *J of Neurological Sciences* 326 (2013) pgs 59-63 describe a prospective observational cohort study using a visual assessment tool to identify concussions that occurred throughout a season of a club level premier team of the New Zealand amateur rugby union. Researchers first administered a previous concussion history questionnaire to each of the 37 players (age;  $22.0 \pm 4.0$  yr.), a baseline Post-Concussion Symptom Scale (PCSS), and two trials of the King-Devick (K-D) visual screening test to obtain baseline readings prior to any match participation. Over the course of the season, all players were to complete a K-D test every post-match to test for unrecognized concussion incidents and any players who exhibited any signs of concussion or were suspected of having a head injury were removed from play and administered the K-D test. Additionally, in order to address the concern of fatigue as a contributing factor to the decline of a K-D score, players were administered the K-D test two minutes after a modified repeat high intensity endurance test (RHIET), which included a series of intensive sprints.

The baseline evaluation tests showed significantly more players (81.1%) reporting a previous sport related concussion than those who did not report a previous concussion, with an average of  $4.0 \pm 2.8$  concussions per player in the



previous three years. Over a season of 24 games with a match exposure of 478.8 hours, there were a total of 22 recorded concussive incidents. Five concussive incidents were witnessed (11 per 1000 match hours) and 17 unrecognized concussive incidents (37 per 1000 match hours) were reportedly identified with the K-D test (Table 1 from paper). A decline in K-D test taking time of about 5 seconds was indicative of changes in oculomotor function associated with mild-traumatic brain injury. These results are significant in that they show a large disparity between witnessed and identified concussions and unrecognized concussive incidents with meaningful head injury, which when combined amount to a ten-fold increase in the previously reported concussion injury rate. Further, the results of the K-D test following RHIET showed a lowering of the baseline by a mean of 1.2 seconds, which suggest that fatigue does not contribute to a longer K-D test time and actually improved K-D score post exercise.

The need for sideline rapid assessment of mild head injury is fundamental to limiting the deleterious effects of repeated impacts to the head. The great majority of athletes are at the youth sports level and not in collegiate or professional sports, which leaves many important decisions to be made by parents and coaches on the sideline. This structural element of sport is unlikely to change since allocating medically trained people to youth sports will require unavailable financial resources. Accordingly, empowering adults to administer a simple, rapid, yet effective test is paramount to preventing repeated head injury. As increasing evidence suggests that even mild impact to the head can lead to accruing neuropathology, it may be prudent to routinely perform sideline testing for players involved in even modest collisions. This could help avoid return to play of athletes with sub-concussive impacts as knowledge about head injury continues to evolve.

### Summary Points:

- ✓ Sideline tools are necessary in order to detect concussions in amateur league and youth sports.
- ✓ 37 rugby players were administered the K-D Test prior to the start of the matches, after each match, and instances of any head trauma during a match. There were 5 witnessed concussions and 17 unrecognized concussions, which were all identified with the K-D Test.
- ✓ Physical fatigue did not worsen K-D scores therefore it is a reliable test to administer after intense physical exercise.
- ✓ The K-D Test is a reliable, repeatable, rapid sideline tool that may be administered by lay persons.



Br J Sports Med. 2013; 47:250-258.

### **Consensus Statement on Concussion in Sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012.**

McCrory P, Meeuwisse WH, Aubry M, Cantu B, Dvorak J, Echemendia RJ, Engebretsen L, Johnston K, Kutcher JS, Raftery M, Sills A, Benson BW, Davis GA, Ellenbogen RG, Guskiewicz K, Herring SA, Iverson GL, Jordan BD, Kissick J, McCrea M, McIntosh AS, Maddocks D, Makhadmeh M, Purcell L, Putukian M, Schneider K, Tator CH, Turner M.

### **How can the SCAT2 be improved?**

It was agreed that a variety of measures should be employed as part of the assessment of concussion to provide a more complete clinical profile for the concussed athlete. Important clinical information can be ascertained in a streamlined manner through the use of a multimodal instrument such as the Sport Concussion Assessment Tool (SCAT). A baseline assessment is advised wherever possible. However, it is acknowledged that further validity studies need to be performed to answer this specific issue. A future SCAT test battery (ie, SCAT3) should include an initial assessment of injury severity using the Glasgow Coma Scale (GCS), immediately followed by observing and documenting concussion signs. Once this is complete, symptom endorsement and symptom severity, as well as neurocognitive and balance functions, should be assessed in any athlete suspected of sustaining a concussion. It is recommended that these latter steps be conducted following a minimum 15 min rest period on the sideline to avoid the influence of exertion or fatigue on the athlete's performance. Although it is noted that this time frame is an arbitrary one, the expert panel agreed nevertheless that a period of rest was important prior to assessment. Future research should consider the efficacy for inclusion of vision tests such as the *King Devick Test* and clinical reaction time tests. Recent studies suggest that these may be useful additions to the sideline assessment of concussion.

### Summary Points:

- ✓ The King-Devick Test has been shown to be a valid, reliable concussion screening test in multiple studies and may be incorporated into sideline concussion protocol.



Sports Med. 2014 Apr;44(4):449-71.ports Med. 2014 Jan.

## Assessment, Management and Knowledge of Sport-Related Concussion: Systematic Review

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**Background:** Sport-related concussions are a subset of mild traumatic brain injuries and are a concern for many sporting activities worldwide. **Objective:** To review and update the literature in regard to the history, pathophysiology, recognition, assessment, management and knowledge of concussion. **Methods:** Searches of electronic literature databases were performed to identify studies published up until April 2013. **Results:** 292 publications focusing on concussion met the inclusion criteria, and so they were quality rated and reviewed. **Conclusion:** Concussion is hard to recognize and diagnose. Initial sideline assessment via the Sports Concussion Assessment Tool 3 (SCAT3), Child-SCAT3 or King-Devick test should be undertaken to identify athletes with concussion as part of a continuum of assessment modalities and athlete management. Sports medicine practitioners should be cognisant of the definition, extent and nature of concussion, and should work with coaches, athletes and trainers to identify and manage concussions. The most common reason for variations in management of concussion is lack of awareness of—and confusion about—the many available published guidelines for concussion. Future research should focus on better systems and tools for recognition, assessment and management of concussion. Sport participants' knowledge of concussion should be evaluated more rigorously, with interventions for sports where there is little knowledge of recognition, assessment and appropriate management of concussion.

### Summary Points:

- ✓ Review of literature exploring concussion history, pathophysiology, recognition, assessment, and management.
- ✓ Signs of concussion including loss of consciousness, amnesia, focal neurological abnormalities are often not present, which is why sideline tests including the SCAT3 and King-Devick test should be used to identify athletes with concussion who have less obvious signs and symptoms.
- ✓ Oculomotor function incorporates multiple sensory areas and frequently affected in mild concussion cases.
- ✓ Multiple individual measures should be used to determine when an athlete may return to play. Symptom assessment, neurocognitive function, and oculomotor testing may be used to monitor recovery and progress.



The International Journal of Sports Physical Therapy. Volume 12, Number 3. June 2017.

## A Comprehensive Instrument for Evaluating Mild Traumatic Brain Injury (mTBI)/Concussion in Independent Adults: A Pilot Study

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**Background:** One common component of concussion rehabilitation is a computerized cognitive test free of concomitant physical demands. Healthcare professionals may be able to provide more patient-centered care after a diagnosed concussion if specific areas of impairment are identified and treated, such as the physical aspect of neurocognitive function. **Hypothesis/Purpose:** To evaluate the test-retest reliability of a unique combination of neurocognitive assessment tools currently utilized in concussion assessments into one single, inclusive instrument that measures both neurocognitive

function and physical capability. Study Design: Original research – diagnostic tests. Methods: Fourteen individuals (nine males, age:  $29 \pm 17.9$ , five females, age:  $46.0 \pm 21.5$  years) either with normal cognitive function (NBI) without history of a health event (e.g. cerebral vascular accident/stroke, mTBI) that resulted in brain injury within one year of the study, or who had suffered a health event that has resulted in a medically documented brain injury (BI) participated in the study. Participants completed the full hybrid assessment instrument for a baseline test, then completed a follow-up test using the same instrument within 72-96 hours of baseline. Test-retest reliability was measured using Pearson product-moment correlations of the first and second testing sessions, and a two-way ANOVA (group between factor: NBI and BI and time within factor: session 1 and session 2) was performed on the summative scores to determine differences between each group. Results: Test-retest reliability was strong and statistically significant for both the NBI ( $r = .858$ ,  $p = .014$ ) and the BI ( $r = .967$ ,  $p = .033$ ) groups. There was a significant difference between summative scores for the NBI and BI groups ( $F_{1,20} = 42.325$ ,  $p < .0001$ ). Conclusion: The newly created Comprehensive Instrument for Evaluating Mild Traumatic Brain Injury (CIEMTBI) demonstrates good test-retest reliability and was able to discriminate the results between individuals in the NBI and BI groups. Further research, specifically with different samples, is needed to better determine the reliability and diagnostic accuracy of the instrument.

### Summary Points:

- ✓ The King-Devick test was used for evaluating saccades, attention, concentration, reading ability, and language skills as part of a larger test battery called the Comprehensive Instrument for Evaluating Mild Traumatic Brain Injury (CIEMTBI).
- ✓ The test-retest reliability was strong for both the non-brain injury group ( $r = .858$ ,  $p = .014$ ) and the brain injury group ( $r = .967$ ,  $p = .033$ ).
- ✓ Both groups showed that the outcomes were repeatable and stable between testing sessions.
- ✓ There was a significant difference between the non-brain injured and the brain injury groups with the non-brain injury group performing the K-D Test significantly faster than the brain injury group ( $F_{1,19} = 37.667$ ,  $P < 0.0001$ ) which could allow for improved monitoring of patients with concussion and recovery periods.



Curr Neurol Neurosci Rep. 2012 Oct;12(5):547-59.

### Sports-Related Concussion Testing

Dziemianowicz MS, Kirschen MP, Pukenas BA, Laudano , Balcer LJ, Galetta SL.

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Due to the recent focus on concussion in sports, a number of tests have been developed to diagnose and manage concussion. While each test measures different brain functions, no single test has been shown to quickly and reliably assess concussion in all cases. In addition, most of the current concussion tests have not been validated by scientific investigation. This review identifies the pros and cons of the most commonly used noninvasive tests for concussion in order to provide a more complete picture of the resources that are available for concussion testing. The potential utility of research tools such as the head impact telemetry system, advanced magnetic resonance imaging protocols, and biomarkers are discussed in the context of the currently employed tools.

"The King–Devick (K–D) Test is a rapid number naming test that captures impaired eye movements and saccades, attention, and language. These involve integration of functions of the brainstem, cerebellum, and cerebral cortex. Impaired eye movements and saccades have been shown to correlate with suboptimal brain function, particularly in patients following concussion. Because the K–D test does not require a medical professional and can be administered in 1–2 min, it is practical for sideline use at all levels of sports. While the K–D test has not been as thoroughly studied as other concussion tests, a study of collegiate athletes found that, on average, concussed athletes performed 5.9 s slower than their baseline, whereas controls performed, on average, almost 3 s faster. In another study of boxers and mixed martial arts fighters, those suffering a concussion showed a worsening of the times required to read the three test cards of 5 s or more, as compared with their own baseline. At this time, any worsening of the K–D score from baseline should suggest the presence of a concussion. In addition, K–D scores in studies of collegiate athletes were not negatively affected by prolonged exercise in the form of intense 2-h scrimmage. One important consideration identified with the K–D test was a learning effect associated with repeated testing. Nevertheless, the K–D test has the potential to capture brain impairment not observed in standard neurocognitive testing."

### Summary Points:

- ✓ The K-D test is a fast, easy to administer, sideline screening tool which assesses > 50% of brain pathways in 1-2 minutes.
- ✓ K-D test involves integration of functions of the brainstem, cerebellum, and cerebral cortex.
- ✓ K-D test can be administered by non-medical professionals.

## British Journal of Sports Medicine

Br J Sports Med. 2017; 51:A81

### **King-Devick (K-D) test as a rinkside tool for concussion assessment**

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**Objective** King-Devick test as a rinkside tool for concussion diagnosis. **Design** KD was administered to hockey players immediately after removal from the game with a suspected concussion. Results were compared to baseline. Concussion was suspected with slowing by >5.2 sec.<sup>1</sup> **Setting** Hockey games. **Participants** Hockey players (male/female) – school-based hockey academy and a Canadian junior hockey team **Interventions** Athletic trainers were trained in the use of KD and obtained baseline KD times for players. AT's administered the KD test to hockey players immediately after removal from the game with a suspected concussion. **Main outcome measures** KD time post-injury was compared to the KD time baseline. **Results** During the 2015–16 season, KD testing was collected on players with suspected concussion (42 concussions identified out of 148 players). Of the 42 concussions, 13 had KD sideline testing done immediately post-injury; 8/13 demonstrated >5.2 sec slowing in their KD baseline scores. All were further evaluated with a comprehensive concussion assessment protocol that included symptom scoring-balance assessments-cognitive testing. Concussion was confirmed with this diagnostic approach in 8/8 players with KD times slowed by more than 5.2 sec. **Conclusions** An ideal concussion sideline diagnostic tool should be inexpensive, portable, reproducible, fatigue-tolerant, resistant to test-retest learning and suitable for non-medical personnel. The King-Devick test, that assesses saccadic eye movements, has these characteristics. It can be administered in less than 2-minutes. It has been reported that a post-injury slowing of KD times >5.2 seconds is diagnostic of concussion. Sideline/rinkside KD testing with > 5.2 sec slowing compared to baseline results accurately identified concussion with 100% accuracy.

### Summary Points:

- ✓ The K-D Test is an ideal sideline tool that is inexpensive, portable, reproducible, fatigue-tolerant, and suitable for non-medical personnel.
- ✓ It assesses saccadic eye movement and can be administered in less than 2 minutes.
- ✓ In this study of school-based academy and Canadian junior hockey, rinkside K-D testing accurately identified concussion.

## British Journal of Sports Medicine

Br J Sports Med. 2017; 51:A81-82

### **Pre-season concussion testing in high school students with academic difficulties or attention deficit hyperactivity disorder**

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**Objective** Learning disabilities and/or ADHD are considered to be important risk factors or modifiers for concussion assessment and management. The purpose of this study was to examine cognition and symptom reporting in high school



students with academic difficulties or ADHD and compare to those without at baseline. **Design** Retrospective analysis of three measures routinely given as part of a high school yearly concussion baseline protocol. **Setting** The library of a high school in Westchester County, NY. **Participants** A sample of 143 high school students who participate in collision/contact sports [Age M (SD)=15.4 (1.2); Boys=78, 54.5%] completed baseline testing. **Main results** Non-parametric tests were used because of violations of normality. High school students with academic difficulties or ADHD (n=21) were compared to controls (n=122) on King-Devick, SAC, ImPACT Cognitive Composite scores, and Total Symptom ratings. Students with LD or ADHD performed significantly more poorly on King-Devick (p=0.003; d=0.79), Visual Motor Speed Composite of ImPACT (p=0.007; d=0.79), and reported more symptoms at baseline on the Post-Concussion Scale (p=0.005; d=0.59). No significant differences found between groups on SAC (p=0.11; d=0.36) or ImPACT Verbal Memory (p=0.54; d=0.16), Visual Memory (p=0.20; d=0.26), or Reaction Time (p=0.14; d=0.55) Composites. **Conclusions** To our knowledge this is the first study to examine performance on three different baseline measures. High school students with academic difficulties or ADHD performed more poorly on King-Devick, the Visual Motor Speed Composite of ImPACT, and reported more symptoms at baseline. Findings suggest these students need to be monitored for specific post injury changes. This study was approved by the Committee for Human Rights Research, Burke Rehabilitation Hospital, White Plains, NY, USA. Protocol # BRC-455.

### Summary Points:

- ✓ High school athletes with learning disability and/or ADHD performed more poorly on the K-D Test at baseline compared to controls. This highlights the importance of establishing an individual pre-injury baseline for comparison during concussion screening and recovery monitoring.



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### **Impact monitoring and King-Devick ocular testing provide a relatively simple process for objectively identifying and managing concussion in sports participants**

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**Objective** This study presents data using multimodal assessment via impact sensors and oculomotor function to quantify neurophysiological changes in the acute period following concussion. **Design** Cohort study. **Participants** Data on impact magnitude and frequency were collected with a wireless head impact sensor (XPatch1) worn by senior amateur rugby players participating in a domestic season. King-Devick Tests<sup>2</sup> were performed pre-season and after significant impact scores (PLA>100 g, PRA>10,000 rads/sec/sec). Participants underwent a one hour baseline assessment of balance, cognition and transcranial magnetic stimulation testing. Following concussive episodes or significant head impacts (as measured by impact sensors), players were re-tested to elicit any differences and to assist in providing objective criteria for the return to play process. **Interventions** Any impact that resulted in a witnessed concussion or that was suspected on the basis of significant impact scores required post-match testing utilising the King-Devick test to help determine appropriate return to play readiness. **Outcome measures** Impact number, peak linear and peak rotational acceleration, risk weighted exposure. Time and errors completing the King-Devick test. **Main result** 20 concussions were detected in all, of which only 3 were witnessed (2 players unconscious on the field, one with balance disturbance resulting in removal from play). **Conclusions** A combination of regular impact monitoring and King-Devick Ocular testing provides a relatively simple process for objectively identifying and managing concussion in sports participants.

### Summary Points:

- ✓ The K-D Test is useful in objectively identifying and managing concussion in sports participants.
- ✓ It is particularly helpful in detecting unwitnessed head injuries which comprised the majority of the diagnosed concussions in this study (17/20) compared to only 3 witnessed injuries with overt concussion symptoms.

## Use of the SCAT-3, Child SCAT3, and King-Devick in concussion assessment of youth hockey players

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**Objective** Currently youth sports hockey programs do not adhere to concussion protocols. The purpose of this study was to examine the relations between performance of two sideline assessments. **Design** Retrospective analysis of two measures given as part of a youth travel hockey program. **Setting** Ice hockey skating facility in Westchester County, NY (USA). **Participants** A sample of 121 youth hockey players participated. All of the athletes were administered the King-Devick, SAC (ages 13-18) and Child SAC (ages 10-12) at baseline, sideline, and once symptom free. **Main results** Mean age was 13.2 (SD=1.2) and there 118 were boys (97.5%). The majority of sample had zero self-reported past concussion (n=113; 93.3). Fourteen athletes sustained concussions. Worse King Devick scores were associated with overall worse SAC and Child SAC Concentration and Delayed Memory scores. For every 1-point reduction in SAC Delayed Memory Score, there was a worsening of King Devick time score of 5.3 seconds (95% CI 5.0, 9.5,  $p<0.001$ ) for children ages 13–18, and a time score difference of 5.8 seconds for children ages 10–12 (95% CI 5.9,  $p<0.001$ ). In examining SAC total score, a 1-point decrease was associated with King Devick score worsening of 2.0s (95% CI 0.5, 4.0,  $p=0.01$ ). Most common symptoms were headache and fatigue for all ages. Once symptom free, there was a trend toward improvement on both measures compared to baseline. **Conclusions** This study reaffirms prior studies that both King Devick and SAC are effective combination clinical tools that assess athletes with suspected concussion.

### Summary Points:

- ✓ The K-D Test was associated with SAC and Child SAC Concentration and Delayed Memory scores.
- ✓ Following concussion injury, there was a trend toward improvement on K-D Test as patients became symptom free.
- ✓ The K-D Test and SAC are an effective combination of clinical tools to assess athletes with suspected concussion.

## Concussion diagnosis: the King-Devick test in the Canadian Football League

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**Objective** To conduct a sensitivity analysis of the King-Devick (K-D) test in professional football. **Design** Prospective cohort. **Setting** Professional football. **Participants** 269 professional football players from the Canadian Football League (CFL). There were 24 concussions to analyse. **Intervention** The K-D test was added to the existing CFL concussion protocol (medical and SCAT3). All participants completed K-D assessments at baseline, at the time of injury/concussion (TOI), and at medical clearance prior to return to play (RTP). 20 controls were re-tested post-baseline. **Outcome measures** K-D scores were analysed to construct a sensitivity analysis. **Main results** TOI K-D results were significantly higher (mean=50.21, range: 35.4–107.4) than baseline K-D results (mean=44.3, range 28.4–66.4;  $p<0.01$ ). TOI K-D results yielded 94% sensitivity and 80% specificity for diagnosing concussions. Four groups emerged from the TOI data. In Group 1, 4/4 were asymptomatic within 24 hours and scores were better (lower) than baseline; Group 2 were asymptomatic within 72 hours and 8/9 had abnormal (poorer) scores; Group 3 were asymptomatic within 11 days and 5/5 had abnormal scores. Group 4 were symptomatic by season's end and 4/4 had abnormal scores. 18/18 players who RTP had better K-D scores than baseline prior to RTP. **Conclusions** The K-D test proved to be useful for concussion diagnosis. Interestingly, the players in Group 1 had normal TOI K-D scores and were asymptomatic in <24 hours. More research is needed and the CFL will continue this next season.

## Summary Points:

- ✓ During the Canadian Football League season, data from 24 concussions were analyzed.
- ✓ The K-D Test performance at the time of injury was significantly higher (worse) than baseline.
- ✓ The K-D Test yielded a 94% sensitivity and 80% specificity for identifying concussive injury.
- ✓ The K-D Test proved to be useful for concussion detection.



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### The effects of age and learning disabilities in the King-Devick test in adolescent ice-hockey players

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**Objective** King-Devick (K-D) is becoming a popular screening test for sport concussion. Rapid number naming may be impaired in developmental dyslexia and other learning disabilities (LD). The aim was to study the interaction of age and LD in K-D in adolescence. The hypothesis was that those with LD perform more poorly on the test regardless of age.

**Design** A case-control, cross-sectional nation-wide study. **Setting** Pre-season 2015–16 baseline tests in all junior teams in the Finnish ice hockey League. **Participants** A total of 805 male adolescents aged 12–21 (divided in 7 age groups), 75 of them reported LD. **Outcome measures** The K-D performance was measured twice. Time in the three subtests was combined to produce a sum score. Sum scores, and their difference, were used as outcome measures. **Main Results** In the youngest age group the mean of the K-D second trial was 49.7 (48.3–51.0, 95% confidence intervals) and in the oldest age group 44.7 (42.9–46.5). In a two-way ANOVA those with LD performed poorer ( $p=0.014$ ,  $\eta^2=0.008$ ) but there was no interaction between age and LD. Similarly, a repeated analysis of covariance yielded a significant main effect for the trial ( $p<0.001$ ,  $\eta^2=0.042$ ) and for LD ( $p<0.001$ ,  $\eta^2=0.026$ ) but not for their interaction when the effect of age was controlled.

**Conclusions** Adolescent players improve their performance in K-D with age, but those with learning disabilities remain slower despite maturation. If K-D is used as a single test for screening, and no baseline data is available, this needs to be recognised.

## Summary Points:

- ✓ Adolescents improve their performance in K-D Test with age underscoring the need for annual baseline establishment.
- ✓ Children with learning disabilities perform worse on K-D Test at baseline highlighting the limitations of using normative data and the importance of using individualized performance for comparison both for sideline detection and clinical monitoring of concussion.



Platform Presentation at the American Medical Society for Sports Medicine 2017 Annual Meeting

### Utility of King-Devick Test as a Concussion Screening Tool in Middle School Football Players

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**Purpose:** Concussion is the most common type of traumatic brain injury and results from impact or impulsive forces. Due to the variability and subtlety of symptoms, concussions may go unrecognized or ignored, especially if pressure is placed on an athlete to return to competition. These factors indicate a reliable and rapid screening tool is needed. The King-Devick (KD) test, a rapid concussion screening test, has been validated in collegiate and high school athletes. We report on a prospective study designed to test the feasibility of using this test as a screening tool in middle school football players. **Methods and Study Design:** 62 male athletes from four local middle school football teams were recruited to participate. Athletes were given baseline testing prior to competition. Standard team protocol was used to diagnose concussions. Immediately after diagnosis, the test was re-administered. For comparison, non-concussed athletes also had repeat testing performed throughout the season. **Results:** Seven diagnosed concussions occurred

during one football season. In all seven concussed players, the cumulative read times for the KD test were significantly increased ( $p = 0.004$ ). Testing of non-concussed athletes revealed minimal, but significant change in read times. In these players, read times were decreased compared to baseline, in what has been termed a "learning effect". **Conclusions:** Despite this "learning effect", the KD test appears to be a suitable sideline screening tool for concussion in middle school football players. **Significance of Findings:** Screening tools, such as the KD test, appear to be valid in younger age groups. Utilization of such screening tools may be important in early identification of TBI and alteration of the normal progression of such problems for lifelong athletes.

### Summary Points:

- ✓ The King-Devick (KD) test, a rapid concussion screening test, has been validated in collegiate and high school athletes.
- ✓ All concussed players ( $n=7$ ) had significantly increased in KD test cumulative times.
- ✓ Non-concussed athletes revealed decrease in KD test time, attributed to the learning effect.
- ✓ K-D Test is a suitable sideline screening tool for concussion in middle school football players.



Platform Presentation at the American Medical Society for Sports Medicine 2017 Annual Meeting

### **King-Devick Test Time Varies by Testing Modality**

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**Purpose:** To determine if King-Devick Test (KDT) time is consistent across two common testing modalities: iPad application (KDT-iPad) versus hand-timed spiral-bound cards (KDT-cards) **Methods and Study Design:** KDT times ( $n = 2,331$ ) were obtained from athletes' baseline assessment during their first year participating at five sites in the Concussion Awareness, Research, and Education (CARE) Consortium. KDT times were standardized by excluding ( $n=22$ ) times which were three standard deviations (SD) or more above the mean (41.1 seconds, range 24.0-112.0, SD = 6.9). The 2,309 remaining KDT times were analyzed based on their modality; either 1) the KDT-iPad ( $n = 705$ , 56% male, mean age = 19.9) which uses the internal iPad clock to time the test, or 2) the KDT-cards ( $n = 1,604$ , 52% male, mean age = 20.0) which are timed by a human test administrator using a standard stopwatch. Differences in means of each modality were compared using Student's T-test. **Results:** KDT-iPad times (mean = 43.0 seconds, 95% CI = 42.8-43.3, SD = 7.0) were significantly slower (2.8 seconds; 95% CI = 2.2-3.4) than KDT-cards times (mean = 40.2 seconds, 95% CI = 40.1-40.4, SD = 6.7) ( $t = -9.0$ ,  $p < .001$ ). **Conclusions:** Baseline KDT times are slower when the test is administered using the iPad application versus the hand-timed spiral-bound cards. **Significance of Findings:** Baseline and post-injury KDT assessments should be performed using the same modality (iPad application or hand-timed spiral-bound cards) given significant timing differences between modalities.

### Summary Points:

- ✓ Baseline and post-injury KDT assessments should be performed using the same modality given significant timing differences between modalities.



Poster Presentation at the American Medical Society for Sports Medicine 2017 Annual Meeting

### **Relationship between the King-Devick Test (KDT) and Commonly Used Concussion Tests**

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**Purpose:** To explore relationships between KDT and other concussion tests at baseline. **Methods and Study Design:** Baseline concussion test scores were obtained from the Concussion Awareness, Research, and Education (CARE) Consortium for the KDT (mean=41.1 seconds, standard-deviation(SD)=6.9, range=24.0-112.0); SCAT3 Symptom Evaluation [total, severity]; Brief Symptom Inventory-18 [anxiety, depression, somatization]; Balance Error Scoring System [firm-surface, foam-surface]; Standardized Assessment of Concussion (SAC) [orientation, immediate-memory, concentration, delayed-memory]; Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) [verbal-memory, visual-memory, visual-motor speed, reaction-time]; and the Vestibular-Ocular Motor Screening tool [ $\Delta$ -score, dichotomized>2, mean-convergence]. Data were analyzed from athletes' first year in CARE (n=2,331, mean-age=20.0yrs, SD=1.5, range=17.3-30.1). Fifty-five subjects were excluded as outliers on KDT and ImPACT. Pearson bivariate correlations were used to assess relationships between KDT and the other tests. SAC-immediate-memory (r=-.069, p=.002), SAC-concentration (r=-.219, p<.001), ImPACT-verbal memory (r=-.049, p=.028), ImPACT-visual-motor speed (r=-.271, p<.001) and ImPACT-reaction-time (r=.169, p<.001) significantly correlated with baseline KDT times. These were used as predictors in a hierarchical regression model (n=1,962). **Results:** The regression model explained 10.5% (r<sup>2</sup>=.105, small effect size) of the variance in KDT baseline times with SAC-concentration ( $\beta$ =-.168, p<.001), ImPACT-visual-motor speed ( $\beta$ =-.221, p<.001), ImPACT-reaction-time ( $\beta$ =.054, p=.029) and ImPACT-verbal-memory ( $\beta$ =.056, p=.014) being significant predictors of baseline KDT times. **Conclusions:** Better baseline SAC-concentration, ImPACT-visual-motor speed and ImPACT-reaction-time predicted better baseline KDT times. Conversely, better ImPACT-verbal-memory predicted worse KDT times. However, the effect sizes for these relationships were small. **Significance of Findings:** Results demonstrate small associations at baseline between KDT and other concussion tests, but significant variance in KDT performance (almost 90%) was not explained by any of these associations, suggesting KDT may contribute unique information to baseline concussion assessments.

### Summary Points:

- ✓ K-D Test performance was significantly correlated with SAC immediate memory, SAC concentration, ImPACT verbal memory, ImPACT visual motor speed and ImPACT reaction time.
- ✓ Regression models only explained 10% of the variability in KD baselines. Therefore findings suggest that K-D measures a construct not related to other commonly used concussion assessments at baseline.
- ✓ The K-D Test should be used in conjunction with other measures as part of a comprehensive assessment battery.



Poster Presentation at the American Medical Society for Sports Medicine 2017 Annual Meeting

### The Effect of Moderate Levels of Physical Activity on the Performance of Baseline Concussion Tests in an Athletic Pediatric Population

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**Purpose:** There is a paucity of validated outcomes tools in the pediatric population to aid in the diagnosis or prognosis of concussion. This study examined the baseline test performance of 3 concussion assessments and investigated the effect of moderate levels of physical activity on test reliability. **Methods and Study Design:** Youth (ages 6-17) actively participating in sports were eligible for study participation. Subjects with a recent history of concussion or current LE injury were excluded. Testing was administered immediately before a training session, practice, or game and included the King Devick (KD), clinical reaction time test (CRT), and postural control assessment (PC). The KD and CRT tests were performed using previously published protocols. PC testing consisted of one 60s trial standing relaxed with eyes closed on a force plate. During a second trial, subjects also completed a Batting Montague (categorization) test. Testing was repeated after completion of the subjects' physical activity session. **Results:** Sixty-six subjects (ages 6-15) were enrolled in the study. Paired samples t-tests of the KD and CRT tests pre to post physical activity indicated no differences: KD (d=0.44+1.67, p=0.80); CRT (d=4.02+3.05, p=0.19). Similarly, no differences were observed for PC measures pre to post physical activity for mean path length (p=0.37) or velocity (max, min, av) in the resting or dual task state. Higuchi's fractal dimension, a measure of system stability were found to differ pre to post physical activity (HFDx p < 0.01; HFDy p=0.01). Model analysis by age group (6-9 or 10-15) revealed no significant differences across ages. **Conclusions:** This study supports preliminary reliability of KD, CRT, and PC test measures in an athletic pediatric population.

Moderate amounts of physical activity as encountered in routine training did not alter test performance. Future studies will need to examine the effect of concussive injury and other confounders on test performance.

### Summary Points:

- ✓ K-D Test is reliable in an athletic pediatric population.
- ✓ Physical activity commonly encountered in routine training did not alter K-D Test performance.



Poster Presentation at the American Medical Society for Sports Medicine 2017 Annual Meeting

### **Visual Performance Testing in Children and Adolescents with ADHD**

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**Purpose:** In the United States, ADHD is estimated to affect 5.4 million children between 6-17 years old. It is the most prevalent pediatric neurodevelopmental disorder. The King-Devick (K-D) test is a vision-based assessment of rapid number naming that requires saccades and visual processing. In sideline testing of young athletes with concussions, the K-D test demonstrated higher score times after a concussive injury as compared to the baseline pre-season scores. ADHD, like concussion and mild TBI, has been linked with visual pathway dysfunction. Our investigation looked at whether children with ADHD scored worse or similar to age-matched controls. **Methods and Study Design:** Our prospective study looked at children with ADHD and their age-matched controls in patients diagnosed with ADHD between ages 5-21. Analysis compared K-D scores of patients with ADHD to those scores of student-athlete controls matched for age and gender. Data analysis was done with logistic regression, ROC curves and t-test. **Results:** Among 134 participants in this study, ADHD vs. control was significantly associated with higher K-D scores ( $p < 0.001$ ). K-D showed a greater capacity to distinguish ADHD in participants older than 11 years of age when compared to controls. Participants with a diagnosis of ADHD required an average of 14 seconds longer to complete the K-D test compared to controls. Stimulant medication use was not associated with differences in K-D scores within the ADHD group. **Conclusions:** This study illustrates that visual pathways might be utilized differently in children and young adults with ADHD compared to controls. **Significance of Findings:** Given the difference in baseline K-D scores of patients with ADHD, this study can have implications for assessing concussions. Different baseline norms may be needed in the management of concussions in athletes with ADHD.

### Summary Points:

- ✓ Visual pathways might be utilized differently in children and young adults with ADHD compared to controls.
- ✓ Norms should not be used for sideline concussion screening as variables such as age and ADHD diagnosis can affect performance. Comparison against individual baseline should be used and is supported by the literature.
- ✓ Caution should be used when considering use of baseline norms in the clinical management of concussion.



Poster Presentation at the American Academy of Neurology 2017 Annual Meeting

### **Year to Year Reliability of the King Devick Test in Collegiate Student-Athletes: An NCAA/DoD Grand Alliance Report**

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**Objective:** To determine the year to year reliability of the King Devick (KD) test in collegiate student athletes.

**Background:** The KD test is an emerging assessment for the identification of sports-related concussions and has been incorporated as a “Level B” assessment in the NCAA/DoD Grand Alliance. A subtle improvement of 2-3 seconds is

expected in acute repeat administrations; however, the reliability over a year has not been established. **Design/Methods:** There were 830 NCAA collegiate student-athletes (Age: 20.2 + 1.3 years old, Height: 180.0 + 11.1cm, Weight: 82.6 + 21.5kg) from five institutions who performed the KD test annually for two years as part of the NCAA/DoD CARE protocol. All participants performed the KD test according to recommended protocols, two trials each year, and tests were performed prior to each participant's intercollegiate athletic season. The outcome measure of interest was the fastest time without errors each year. A Pearson correlation compared the reliability of the measure and reliable change index (RCI) was calculated. **Results:** There was a significant positive correlation between the two years (Year 1: 40.8 + 7.4 seconds and Year 2: 38.75 + 7.7 seconds,  $r=0.827$ ,  $p<0.001$ ). The mean improvement was 2.01 seconds, mode was 2.0 seconds, and median improvement was 2.2 seconds. The RCI was 8.47 seconds and 62 participants (7.5%) exceeded the RCI with most (48/62, 77.4%) having a faster score in year 2. **Conclusions:** These results suggest that the KD is reliable from year to year and a modest improvement in performance of about 2 seconds should be expected with repeat administration in the second year. Clinicians should not that a small percentage of individual will demonstrate changes exceeding the RCI with repeat administration and future investigations should seek to identify determinants of performance variability. **Study Supported by:** NCAA/DoD Grand Alliance: W81XWH-14-2-0151

### Summary Points:

- ✓ K-D Test is reliable from year to year with a modest improvement in performance of about 2 seconds with repeat administration.



Poster Presentation at the American Academy of Neurology 2017 Annual Meeting

### **Between Trial Reliability of the King Devick Test**

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**Objective:** To evaluate the between trial reliability of the King-Devick (KD) test. **Background:** The KD test is a reading efficiency test meant to provide an assessment of cognitive visual processing. Administration of the test requires two trials; however the reliability of trial one to trial two is unknown. **Design/Methods:** 3193 KD test scores were evaluated from 2,373 NCAA athletes (1,110 female, 1,263 male, 20.22±2.32 years old, 70.28±4.51 inches, 177.72 ±76.36 lbs.) from five institutions that underwent baseline KD testing over a two-year period as part of the NCAA/DoD CARE protocol. All testing was completed prior to their athletic season. Subjects were instructed to read aloud numbers from three cards as quickly as possible without making errors. The cumulative time from all three cards was the score for that trial with two trials being conducted. The outcome measures were the times for trial one and trial two. A Pearson correlation and reliable change index (RCI) were calculated. **Results:** There was a significant positive correlation between trial one (43.05±7.97 seconds, range 23.84 – 103.8 seconds) and trial two (40.7 sec ± 7.46, range 22.38 – 86.55 seconds) with an  $r$  of 0.882,  $p<0.001$ . A majority of subjects improved on the second trial ( $n=2452$ , 77%) with 25 subjects receiving the same score and 716 (22%) scoring worse on the second trial. The mean improvement was 2.35 seconds with a median of 2.2 seconds. The RCI was calculated at 7.59 seconds with 219 (7%) of the subjects exceeding the RCI. **Conclusions:** The results of the study suggest that the KD test is stable across both trials at baseline. However, a modest learning effect of approximately 2.3 seconds should be expected on the second trial suggesting the second trial is necessary for an accurate baseline score.

### Summary Points:

- ✓ K-D Test is stable across both trials at baseline with a modest learning effect of approximately 2.3 seconds should be expected on the second trial suggesting that the second trial is necessary for an accurate baseline score.



Poster Presentation at the American Academy of Neurology 2017 Annual Meeting

## Sensorimotor Vision Screening in a Random Sample of Recently Deployed Soldiers With and Without a History of

**Mild TBI** Amy Chang<sup>1</sup>, Alan Finkel<sup>2</sup>, Karen Schwab<sup>3</sup>, Lisa Brenner<sup>4</sup>, Scott Klimp<sup>5</sup>,

Henry McMillan<sup>6</sup>, Ann Scher<sup>7</sup> <sup>1</sup> Hennepin County Medical Center, <sup>2</sup> Carolina Headache Institute, <sup>3</sup> DVBIC, <sup>4</sup> U.S. Department of Veterans Affairs, <sup>5</sup> U.S. Army, <sup>6</sup> Intrepid Spirit Center, <sup>7</sup> USUHS Dept PMB

**Objective:** To determine if simple screening tests of visual function are sensitive to a history of mTBI in recently deployed soldiers. **Background:** Mild traumatic brain injury (mTBI=concussion) can result in persistent neurological symptoms such as dizziness, headaches, behavioral changes, and sleep disturbances. Vision problems can also stem from these injuries, including difficulty with reading, double vision, and eye strain. Such symptoms are often overlooked in the standard evaluation of mTBI. We evaluated the performance of three simple tests of visual function in a non-clinical cohort of recently deployed soldiers in order to determine whether these tests distinguished between soldiers with and without a history of mTBI. **Design/Methods:** Participants were a random subset of recently deployed soldiers returning to Fort Bragg, NC. We evaluated near point of convergence break, amplitude of accommodation, and saccadic eye movement (King Devick) during a structured clinical examination. Mean test values / proportions with clinically significant results were compared between soldiers with (cases) and without (controls) a history of mTBI sustained during this last deployment. **Results:** Participants (n=406; 122 mTBI cases; 284 controls) were primarily male (89%) and young (28 years of age). Compared to controls, those with a history of mTBI did worse on all visual tests and had approximately doubled odds of having clinically relevant results. Sub-group analysis showed that mTBI with reported loss of consciousness was particularly associated with poor performance on these tests. **Conclusions:** Three simple tests of visual function are sensitive to a history of mTBI in this non-clinical sample of recently deployed soldiers. Since these tests are quick, inexpensive, and easy to administer, they may be useful as screening instruments or prognostic biomarkers in studies of non-clinical populations. Study Supported by: Primary funding was provided by the Center for Neuroscience and Regenerative Medicine (CNRM) and the Defense Medical Research and Development Program (DMRDP).

### Summary Points:

- ✓ K-D Test is sensitive to a history of mTBI in this non-clinical sample of recently deployed soldiers
- ✓ K-D Test has utility as a screening and prognostic instrument.



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Poster Presentation at the Sports Neuropsychology Society 2017 Annual Meeting

## Utility of Ocular and Vestibular Screening Measures for Projected Concussion Recovery Duration

Worts P, Datoc A, Puhr J, Burkhardt S

**Purpose:** Recently, the King-Devick (K-D) test (Galletta et al., 2011) and Vestibular/Ocular Motor Screening (VOMS) (Mucha et al., 2014) have demonstrated the ability to detect impairments following concussion. To date, there is limited evidence related to concussion recovery duration and vestibular and ocular measures (Anzalone et al., 2017; Corwin et al., 2014). The purpose of the study was to determine if there is a threshold for clinical concussion tools to identify prolonged recovery ( $\geq 21$  days) based on initial visit test performance. **Methods:** 84 student-athletes (48 males/36 females;  $15.2 \pm 1.4$  years), seen within 7 days of injury, completed the King-Devick test and Vestibular Ocular Motor Screening during their clinical exam following a sport-related concussion. Chi-square test for homogeneity was used to compare group proportions of patients identified as abnormal based on test performance. Significance was set at  $p < 0.05$ . **Results:** Chi-square test revealed that athletes with a K-D test time of  $\geq 65$  seconds were 4.08 times (95% CI, 1.59 to 10.5;  $p = 0.003$ ) higher odds for prolonged recovery. There were no statistically significant findings for a +2 symptom provocation on the VOMS ( $p = 0.257$ ) and NPC distance  $\geq 5.5$  cm ( $p = 0.491$ ). **Conclusions:** Our findings suggest that K-D test times below the 2nd percentile ( $> 64.5$ s) in healthy athletes (Vartiainen et al., 2014) may be a viable cutoff for identifying prolonged recovery following a sport-related concussion. Future research should determine if these findings remain consistent in collegiate athletes and a larger high school athlete cohort.

### Summary Points:



- ✓ K-D Test is useful in identifying individuals at higher risk for prolonged recovery following sport-related concussion
- ✓ In this cohort, injured athletes with an initial KD test performance time of  $\geq 65$  seconds were at 4.08 times higher odds for a prolonged recovery.



Poster Presentation at the American Academy of Neurology Sports Concussion Conference 2016

## **The King-Devick Test in Mixed Martial Arts: A Pilot Study on the immediate consequences of knock-outs, concussions, and chokes on brain functions**

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**Objective:** There has been considerable attention brought to the detection and evaluation of concussive injuries across many different sports. The Kind-Devick (K-D) test has been utilized as a tool to screen for concussive injury in multiple sports including boxing, mixed martial arts (MMA), hockey, amateur rugby, and high school football. The aim of this study was to determine the effect of training or a brain “event” such as knock-outs (KO), chokes, near chokes, concussions or tap outs on brain function as assessed by the K-D test in adult mixed martial arts athletes.

**Methods:** Adult MMA athletes ( $n = 54$ , mean age  $29.9 \pm 6.9$ ) underwent baseline K-D testing prior to and following a workout or sanctioned fight. Pre workout and pre fight K-D testing was administered prior to practice in the workout group and on the weigh-in day prior to a scheduled fight. Post-practice and post-fight K-D testing was administered immediately following practice or within 10 minutes of fight completion.

**Results:** K-D tests worsened (longer duration) in athletes that had an “event” ( $N = 13$ ) ( $44.8 \pm 7.0$  s vs  $49.5 \pm 8.2$ , median change  $-6.0$  seconds,  $p = 0.0210$ , Wilcoxon signed rank test). K-D tests improved (shorter duration) following a standard workout or following a fight in which no “event” occurred ( $n = 48$ ) ( $51.1 \pm 11.7$  s vs  $44.5 \pm 6.9$  s, median change  $4.73$  seconds,  $p = <0.0001$ , Wilcoxon signed-rank).

**Conclusion:** Slowing (worsening) of the post-fight K-D test is a reliable method for identifying MMA fighters with significant injury due to a choke, near choke, KO, tap out or concussion. These injuries mimic concussive injury K-D test scores from other contact sports.

### Summary Points:

- ✓ K-D Test performance worsened in athletes with an event (choke, near choke, knock out, tap out or concussion)
- ✓ K-D Test performance improved after workout in the absence of any event
- ✓ Slowing of post-fight K-D Test is a reliable method for identifying MMA fighters with significant injury due to choke, near choke, KO, tap out or concussion.



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Poster Presentation at the Sports Neuropsychology Society 2016 Annual Meeting

Poster Presentation at the American Academy of Neurology Sports Concussion Conference 2016

## **Pre- to Post-Season King-Devick Test Performance in Youth Football Athletes**

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**Background:** Youth athletes are more vulnerable to concussive injury. Professional and collegiate athletics have begun to place neurologists, neurosurgeons, athletic trainers and team physicians on the sidelines for the assessment of head injuries sustained during play. In stark contrast, the majority of U.S. high schools do not have access to athletic training staff and there is an even greater lack of medical personnel at the youth and amateur sports level. This marked disparity underscores the need for a predictive sideline test that can be performed by laypersons to help objectively determine concussive injury and remove an athlete from play, particularly since athletes often under-

report their symptoms.<sup>4</sup> The King-Devick (K-D) Test is comprised of a demonstration card and three test cards that increase in difficulty. The K-D Test of rapid number naming requires vision, eye movements (saccadic, accommodative and vergence), concentration, language function and attention to perform and has been shown to reflect suboptimal brain function.<sup>5</sup> Many recent studies have highlighted the utility of the K-D test on the sideline to detect both concussive as well as sub-concussive injury in high school, collegiate, and professional level athletes and been has demonstrated high sensitivity, specificity, and test-retest reliability. The purpose of this study is to further examine pre and post-season as well as test-retest reliability of K-D Test performance in youth athletes. **Methods:** In this prospective study, youth tackle football athletes (n=178, 100% male, age  $12.06 \pm 0.93$  years [range 10-14 years]) completed pre-season and post-season K-D Test as part of a larger study. Standard published K-D baseline procedures were used for both testing time points. Total K-D Test time was recorded. Athletes with concussion during the season were excluded. **Results:** Mean K-D Test time at pre-season was  $50.12 \pm 10.34$  sec (range 31.65-81.07 sec). K-D Test scores between the pre- and post-season tests demonstrated high test-retest reliability (ICC 0.94, 95% CI [0.80, 0.98]). Inter-individual change from pre-season to post-season demonstrated an improvement in K-D Test time by  $4.87 \text{ sec} \pm 0.49$ . Pre-season K-D Test score improved 3.8 sec with every year increase in age (95% CI [2.3-5.4]  $p < 0.001$ ,  $R^2 = 0.12$ , linear regression). Mean K-D Test time at post-season was  $44.01 \text{ sec} \pm 0.92$  (range 25.31-76.84 sec). **Conclusions:** In this cohort of non-concussed, youth football athletes, K-D Test demonstrated high test-retest reliability. Similar to previously published literature<sup>6</sup>, pre-season K-D Test times improved with age, however there was a wide range of baseline performance in this age group. This data highlights the necessity for (1) establishing individual baselines for comparison rather than relying on normative data and (2) performing yearly baseline testing due to improvement of K-D Test performance with advancing age during childhood and adolescence. Continued prospective studies of the K-D Test as a sideline tool for concussion detection and management in youth athletes and the clinical utility of the test as a surrogate objective marker for recovery are on-going.

### Summary Points:

- ✓ The K-D Test has high test-retest reliability in youth athletes
- ✓ Pre-season K-D Test times
- ✓ It is necessary to establish individual baseline for comparison rather than relying on normative data
- ✓ Important to perform yearly baseline testing due to improvement of K-D Test performance with advancing age during childhood and adolescence



Poster Presentation at the North American Neuro-Ophthalmology Society 2016 Annual Meeting  
Platform & Poster Presentation at the American Academy of Neurology 2016 Annual Meeting

### **Yield of the Clinical Neuro-Ophthalmologic Examination in Patients with Concussion**

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**Introduction:** Due to the widespread nature of ocular motor anatomic pathways, traumatic brain injury and its mildest form, concussion, affect eye movements in many ways. However, the extent to which concussion results in ocular motor deficits detectable on clinical examination is unclear. Existing literature suggests a high incidence of convergence insufficiency, saccadic deficits, and smooth pursuit impairment. We sought to identify the

incidence of ocular motor dysfunction in a multidisciplinary concussion center-based neuro-ophthalmologic practice.

**Methods:** We performed a retrospective chart review of all patients with a concussion-related diagnostic code seen in the practice of four neuro-ophthalmologists between 8/1/2014 and 8/1/2015. Those with pre-existing ocular motor deficits or significant positive neuroimaging findings (i.e. subdural or intracranial hemorrhage, orbital fractures) were excluded from the analysis.

**Results:** Seventy patients with a concussion-related diagnosis were identified. Fifty-eight subjects (mean age  $30.8 \pm 14.7$ , age range 11-65, 30 males, 28 females) met inclusion criteria. Loss of consciousness was documented in 13 (22.4%). Twenty-four (41.4%) reported a history of multiple concussions. The most common symptom was headache (n=36, 62.1%), followed by photosensitivity (n=19, 32.8%). Difficulty reading or using screens were reported in 11 (19%) and 9 (15%), respectively. Ocular motor dysfunction was seen on neuro-ophthalmologic examination in 16 (27.6%) patients;

findings predominantly included convergence insufficiency (n=13, 22.4%). Reduced stereopsis, ocular flutter, impaired VOR cancellation, and gaze-evoked nystagmus were each found in single patients. One patient had square wave jerks, but it was unclear if these were pathologic. Deficits of saccades were not identified by clinical examination. **Conclusions:** Results of this neuro-ophthalmic concussion study are concordant with existing literature showing a fairly high incidence of convergence insufficiency. Interestingly, other eye movement abnormalities were rare and saccadic deficits were not detected, emphasizing the need for additional performance measures or eye movement recordings to capture concussion-related efferent visual deficits.

### Summary Points:

- ✓ A 1-year retrospective chart review of concussion-related diagnostic codes in a neuro-ophthalmology practice was completed.
- ✓ Most common symptoms included headache, photosensitivity, difficulty reading and difficulty using screens.
- ✓ Loss of consciousness occurred in 22.4%.
- ✓ Ocular motor dysfunction was evident in 27.6% and convergence insufficiency was predominant (22.4%).
- ✓ Deficits of saccades were not identified by clinical examination emphasizing the need for performance measures or eye movement recordings to detect these concussion-related efferent visual deficits.



Poster Presentation at the North American Neuro-Ophthalmology Society 2016 Annual Meeting  
Platform & Poster Presentation at the American Academy of Neurology 2016 Annual Meeting

### **Visual Performance of Non-Native versus Native English Speakers on a Sideline Concussion Screen: An Objective Look at Eye Movement Recordings**

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**Introduction:** The King-Devick (KD) test of rapid number-naming, a sensitive and rapid performance measure, adds a visual dimension to sideline testing for concussion. We performed

a laboratory-based eye movement study during performance of the KD test. We sought to determine if having English as a second language results in slower KD reading times or changes in eye movements. **Methods:** We tested 27 native English speakers (NES) (mean age 32) and 27 subjects for whom English was a second language (ESL) (mean age 34). Participants had no history of concussion. Participants performed a computerized version of the KD. Simultaneous infrared-based videoculographic (VOG) recordings were performed using the Eyelink1000+. A Bilingual Dominance Scale survey, which quantifies primary versus secondary language dominance, was completed by all ESL subjects. **Results:** Digitized KD reading times were significantly prolonged for ESL participants, compared to NES ( $54.4 \pm 15.4$  sec vs.  $42.8 \pm 8.6$  sec,  $p=0.001$ , t-test). Average inter-saccadic intervals (ISI), a combined measure of saccade latency and fixation duration), were significantly longer for ESL participants ( $402 \pm 116.9$  msec vs.  $317.7 \pm 53.9$  msec,  $p=0.002$ , t-test). The total number of saccades for ESL participants was significantly higher ( $149 \pm 28$  vs.  $135 \pm 18$ ,  $p=0.03$ , t-test). **Conclusions:** This study highlights performance disparities that linguistics may impose on rapid number-naming tasks. Concussion screening is best implemented by establishment of pre-season baselines to allow for intra-subject comparisons after impact in sport. If preseason baseline data are unavailable, caution should be taken in comparing non-native English speaker reading times to a NES normative control KD time database.

### Summary Points:

- ✓ Laboratory-based eye movement study completed to determine the effect of English as a second language on the K-D test and eye movement performance.
- ✓ Digitized KR reading times were prolonged for ESL participants.

- ✓ Average inter-saccadic intervals (ISI) represents a combined measure of saccade latency and fixation duration.
- ✓ ISI was longer for ESL participants.
- ✓ Total number of saccades for ESP participants was higher.
- ✓ Disparities that linguistics may impose on rapid number naming highlights the importance of proper concussion screening implementation by establishing individual pre-season baselines to allow for intra-subject comparisons after impact in sport.
- ✓ Caution should be taken in comparing ESL performance to a normative control database.



Poster Presentation at the American Academy of Neurology 2014 Annual Meeting  
**Vision-Based Concussion Testing in a Youth Ice Hockey Cohort: Effects of Age and Visual Crowding**  
 Jennifer Morganroth, BA; Steven L. Galetta, MD; Laura J. Balcer, MD, MSCE  
*Department of Neurology, NYU School of Medicine, NYU Langone Medical Center, NY, NY*

**Objective:** We examined the King-Devick (K-D) test, a vision-based measure of rapid number naming, as a complement to the Sport Concussion Assessment Tool, 3rd edition (SCAT3/Child-SCAT3) for sideline diagnosis in youth athletes. **Background:** Particularly in youth sports, identification of rapid yet simple diagnostic tests for concussion is critical. These rapid tests must be interpreted in the context of developmental status and age. **Methods:** Members of a suburban youth ice hockey league participated in a prospective study to examine three brief rink-side tests: K-D test, Standardized Assessment of Concussion (SAC, cognition) and timed tandem gait (balance). To perform the K-D test, athletes read numbers from three laminated test cards from left to right as quickly as possible. The cards become progressively more difficult due to changes in vertical spacing between lines; this is particularly notable for card 3. **Results:** Ninety-nine athletes (mean age  $10.8 \pm 3.0$  years, range 6-17 years) underwent pre-season baseline testing for this study. Athletes completed the K-D test in an average of 56.5 seconds (best of two baseline trials, range 27.5-159.8 seconds). Average total SAC scores were 26/maximum 30 points (range 17-30); average best of four trials for timed tandem gait was  $15.9 \pm 6.0$  seconds. All three tests showed better scores among older athletes ( $p < 0.001$  for all, linear regression). Time scores for K-D were significantly slower (worse) for younger athletes ( $p < 0.001$ ). This association of worse K-D scores with younger age was most evident for K-D card 3, the card with the greatest degree of vertical visual crowding (average of 3.9 seconds slower vs. card 1,  $p < 0.001$ , linear regression). **Conclusions:** Scores for rapid sideline concussion tests may vary with age and developmental status of youth athletes; better scores in this cohort were noted among older players. Visual crowding, an age-dependent inability to perceive objects due to clutter, may in part explain the more dramatic association of slower time scores on test card 3 with younger age for the K-D test.

### Summary Points:

- ✓ 121 hockey players (ages 5-17) performed the K-D test, timed tandem gait (balance), and SAC.
- ✓ Older ages, teens, scored faster (better) on K-D test than younger athletes.
- ✓ Visual crowding may explain the difference in K-D Test performance in younger athletes.
- ✓ Up-to-date pre-season baseline test scores are important due to score differences among age groups.



Platform & Poster Presentation at American Academy of Neurology 2014 Annual Meeting  
**The King-Devick Test is Vastly Superior to the Symbol Digit Modalities Test as a Sideline Determinant of Concussion in Mixed Martial Arts Fighters**

Daniel Kantor, MD *Neurologique, Ponte Vedra, FL USA*

**Objective:** To compare the Symbol Digit Modalities Test (SDMT) to the King-Devick (K-D) test as a potential rapid sideline screening for concussion. **Background:** Sports-related concussion is increasingly recognized as a major public



health problem due to potential for neurologic sequelae. Despite recent research that has suggested the potential role of the K-D test as a sideline screening tool for concussion, there remains a need for a rapid sideline test that requires less examiner attention. The K-D test screens for combined impairments in eye movements, attention and language by measuring the speed of rapid number naming on 3 test cards. The written version of the SDMT is based on measurement of the speed of conversion of geometric designs into number responses, and captures impairments of attention, processing speed, eye movements, writing, and other correlates of cerebral dysfunction. **Methods:** The SDMT and K-D test were administered pre- and postfight by a single examiner to 16 mixed martial arts fighters. Changes in SDMT and K-D scores from pre- to postfight were compared for those with head trauma during the fight vs. those without. **Results:** There was a modest correlation between head trauma during the match and whether there was worsening (increase) in K-D scores ( $r=0.54$ ,  $p=0.015$ ), the actual change ( $r=0.42$ ,  $p=0.055$ ) and the percentage change in K-D scores from pre- to postfight ( $r=0.50$ ,  $p=0.025$ ). Only 1 fighter without head trauma had a worsening of K-D score by  $\geq 5$  seconds. There was only small to medium correlation between worsening of SDMT score (decrease) and K-D score. Surprisingly there was no correlation between SDMT scores and concussion during the match. **Conclusions:** This study confirms that the K-D test, but not the SDMT, is reliable in rapidly identifying athletes with head trauma. This suggests that further validation of the K-D test, but not the SDMT, may be valuable in the early detection of concussion.

### Summary Points:

- ✓ Compared K-D scores and Symbol Digit Modalities Test (SDMT) scores among 16 mixed martial arts fighters, pre- and post-fight.
- ✓ There was an overall worsening of K-D scores in fighters with head trauma.
- ✓ There was no correlation between SDMT scores and concussion during the match.
- ✓ The K-D test was more reliable in identifying a change elicited by head trauma in this cohort compared to the SDMT.



Poster Presentation Association for Research in Vision and Ophthalmology 2013 Meeting

### **Concussion Screening in High School Football Using the King Devick Test**

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**Purpose:** To evaluate the effectiveness of the King-Devick (K-D) test, a screening which evaluates saccadic eye movements, to identify football players who may have sustained a concussion during play. Secondary outcomes include evaluating whether performance of K-D testing increases awareness of concussion in high School football players. **Methods:** Forty seven high school football players ranging from freshmen to senior grade levels and all play levels were given a baseline K-D test prior to beginning of the 2012 football season. Each student also filled out a survey gauging their level of awareness of concussion signs and symptoms. During the season, three varsity level players sustained concussions on-field. Each of these players had the K-D test performed within thirty minutes of impact. The concussion diagnosis was confirmed by a neurologist within days of the on-field incident. At the end of the season, the K-D test was again administered to all students. Students also took a post-season survey which was identical to the one they took prior to the start of the season to gauge their awareness of concussion. **Results:** There was very little variance in athletes who did not have concussion when comparing pre- and post-season testing with LOA of 95% and confidence intervals of 95%. Test-retest reliability was analyzed using intraclass correlation coefficients (ICC) between baseline and end of the season data, showing correlation of 0.873 with significance of  $p < 0.05$ . The three football players whose concussion diagnosis was confirmed by a neurologist did in fact demonstrate diminished K-D test performance times within thirty minutes of the on-field injury. Times were diminished by 41% in student 1, 100% in student 2, and 143% in student 3. Regarding the knowledge of concussions survey administered pre- and post-season, paired sample t-tests showed  $p > 0.05$  significance for the question “I would say that my current knowledge level of concussions is very high.” Therefore, it is evident that the football students’ level of awareness of concussion significantly increased throughout the season. **Conclusions:** This study showed that the King-Devick Test can potentially be used as a rapid sideline tool to identify athletes who have potential concussion in a time period of under one minute.

### Summary Points:

- ✓ Assessed the effectiveness of K-D test to identify concussion in high school football players.
- ✓ 3 out of 47 players sustained concussions and performed worse on the K-D Test.
- ✓ Pre- and post-season testing for non-concussed players showed no worsening of K-D test time.
- ✓ K-D testing heightened awareness of concussion.



**Sports Neuropsychology**  
**Society**

Poster Presentation at the Sports Neuropsychology Society 2015 Annual Meeting

### **Improved Performance on the King-Devick Test When Re-Tested After Collegiate Sport Exposure**

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**Purpose:** The King-Devick Test (KDT) is a measure of saccadic eye movement and reading speed that is used as a brief sideline assessment of concussion. The current study evaluates: Changes in KDT performance with repeat testing in a collegiate athlete sample. We hypothesize that slow performers (longest times) will show significantly more improvement from BL #1 to BL #2 than the average and fast performers (shortest times), clinically relevant cut scores characterizing fast, average, and slow KDT times for each gender, and evidence for annual KDT re-baselines.

**Methods:** A retrospective analysis of 131 collegiate athlete player records from the University of Florida Concussion Databank was performed. Athletes in this study performed the KDT at two separate time points separated by at least one full athletic season. All KDT assessments were performed on the KDT iPad application and administered by athletic trainers and team physicians at the University of Florida. Athletes were grouped based on standardized score performances on initial KDT as Fast ( $z \leq -1$ ), Average ( $-1 < z < 1$ ), or Slow ( $z \geq 1$ ). Paired Samples T-test were conducted to determine if changes in group performance from KDT #1 to KDT #2 were significant.

**Results:** Overall, student-athletes completed the KDT significantly faster at BL#2 than at BL#1 ( $p < .001$ ). There were differential improvement rates based on initial baseline classification, such that slow performers (longest times) had significantly more improvement from BL#1 to BL#2 than the average ( $p < .005$ ) and fast ( $p < .001$ ) performers (shortest times). Both male ( $p = .001$ ) and female ( $p < .001$ ) athletes improved from baseline #1 to baseline #2, and both genders showed differential improvement rates based on initial baseline classification. There were no significant differences on initial baseline scores between athletes with a history of concussion and athletes with no history of concussion. **Conclusions:** Athletes improve on the KDT with repeated testing, even with substantial time between assessments. Athletes who perform poorly on initial KDT baseline improve significantly on retesting, while better performers do not show comparable improvements. Athletes with extremely slow baseline scores should be re-tested in order to obtain a more representative performance. These results were consistent across different sports, gender, and concussion histories. Athletes in contact sports show comparable improvements to athletes in non-contact sports with repeated testing. **Significance:** It is recommended that athletes who perform relatively poorly (1 standard deviation slower than average performance, or greater than 50 seconds for males and 53 seconds for females based on our sample) on their baseline KDT assessment be targeted for a repeat administration.

### Summary Points:

- ✓ Athletes improve on the KDT with repeated testing, even with substantial time between assessments.



Poster Presentation at University of Florida College of Medicine 2015

### **An Analysis of Test-Retest Performance of the King-Devick Test and Comparison to Standard Concussion Tests in Collegiate Football Players**

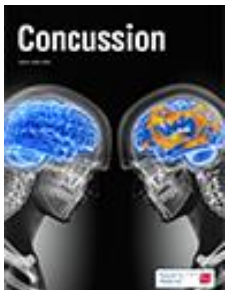
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**Purpose:** The King-Devick Test (KDT) is a measure of saccadic eye motion and reading speed that is widely used as a rapid, sideline assessment of the acute effects of concussion. The purpose of this study was to evaluate: Changes in KDT performance over time and in different settings, differences in KDT performance based on player position, years playing football, and concussion history and concurrent validity of KDT performance with other standard concussion assessment measures. **Methods:** A retrospective analysis of 113 football player records from the University of Florida Athletic Association Concussion Databank was performed. Each athlete completed two KDT baseline assessments (BL#1 and BL#2) either at rest or post-exertion. KDT performance at BL#1 was compared to a simple drop-stick reaction time measure (Clinical Reaction Time or CRT) as well as performance on select components of the computerized Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT™): Visual Motor Speed (VMS), Reaction Time (RT), and Cognitive Efficiency Index (CEI). Information regarding player position, years playing football, and concussion history was also obtained. Positional comparisons were based on positions that are exposed to the highest number of impacts to the head and positions exposed to the greatest magnitude of forces to the head. **Analyses:** Change in KDT performance from BL#1 to BL#2 was analyzed using Paired-Samples T-Tests: Difference in performance based on test setting player position were analyzed using an Independent Samples T-Test. Effect of various demographic variables and relationship with other concussion assessments were analyzed using Pearson Correlations and regression analyses. **Results:** Football players showed significant improvement from BL#1 to BL#2, regardless of concussion history (mean improvement = 3.1 seconds,  $t(69)=5.69$ ,  $p<.001$ ). There was a significant effect of BL#1 performance on degree of improvement at BL#2 ( $F(2,67)=16.64$ ,  $p<.001$ ). Athletes with the slowest (worst) performance at BL#1 improved significantly more than those with Average ( $p<.001$ ) and Fast ( $p<.001$ ) BL#1 times. Both the CRT ( $\beta=.231$ ,  $p=.012$ ) and ImPACT™ VMS ( $\beta=-.348$ ,  $p=.001$ ) were significant predictors of KDT BL#1 performance. There were no significant differences or relationships observed based on test setting, position played, years of football played, or concussion history. **Conclusion:** 1) On average, football players showed improved KDT on their second baseline assessment. Football players with the slowest times at BL#1 showed the greatest improvement at BL#2 relative to those with average or fast times at BL#1. There is evidence to support the validity of the KDT as a clinical measure of concussion assessment based on the observed relationships with the CRT and ImPACT™ VMS measures. Baseline KDT performance does not appear to be affected by test setting, position played, years of football played, or history of concussion. **Significance:** Our results indicate that football players typically improve their KDT times with retesting and there is evidence to support the validity of KDT in concussion diagnosis. Our main finding indicates that it may be necessary to complete multiple KDT assessments in order to achieve an athlete's true BL performance.

### Summary Points:

- ✓ There is evidence to support the validity of the KDT as a clinical measure of concussion assessment based on the observed relationships with the CRT and ImPACT™ VMS measures.
- ✓ Baseline KDT performance does not appear to be affected by test setting, position played, years of football played, or history of concussion.



Concussion. 6 August 2015

### **Variability of the modified balance error scoring system at baseline using objective and subjective balance measures**

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**Aim:** To investigate preseason modified Balance Error Scoring System (mBESS) performance in a collegiate football cohort; to compare scores to an objective mobile balance measurement tool.

**Methods:** Eighty-two athletes completed simultaneous balance testing using mBESS and the King-Devick Balance Test, an objective balance measurement tool. Errors on mBESS and objective measurements in the double-leg, single-leg (SS) and tandem stances were compared. **Results:** Mean mBESS error score was  $7.23 \pm 4.65$ . The SS accounted for 74% of errors and 21% of athletes demonstrated the maximum error score. There was no significant

correlation between mBESS score and objective balance score. **Conclusion:** The high variability and large number of errors in the SS raises concerns over the utility of the SS in identifying suspected concussion.

### Summary Points:

- ✓ Compared the K-D Balance Test to the modified Balance Error Scoring System (mBESS) on 82 collegiate football players.
- ✓ The K-D Balance Test provides an objective, quantitative postural measurement, utilizing a mobile accelerometer.
- ✓ mBESS error scores were highly variable, especially in the single-leg stance (SS) for nonconcussed, asymptomatic athletes.
- ✓ There was no significant correlation between subjective mBESS and the objective K-D Balance Test due to the ceiling effect of the mBESS maximum error score.
- ✓ Objective, quantitative balance measures may improve postural assessments in the setting of concussion.



Poster Presentation at the American Academy of Neurology 2017 Annual Meeting

### **Quantitative Comparison of K-D Balance and Sway Balance™ System Mobile Device Applications**

Chelsea Zhang, Bert Vargas; *UT Southwestern Department of Neurology*

**Objective:** To compare agreement and intra-class correlation of King-Devick (K-D) Balance versus Sway Balance mobile applications. **Background:** Balance assessments are essential in concussion evaluation due to the high incidence of post-concussion balance deficits. Traditional modified Balance Error Scoring System is highly subjective. Objective quantitative balance evaluations K-D Balance and Sway Balance should be explored. **Methods:** Seventy subjects examined at UT Southwestern Medical Center underwent simultaneous K-D Balance and Sway-Balance assessments. Intra-class correlation coefficient (ICC) assesses test retest reliability of K-D Balance. Linear regression analysis and Bland-Altman Plot evaluate the agreement between K-D Balance and Sway Balance scores. **Results:** K-D Balance and Sway Balance scores showed no statistical difference (K-D  $96.0 \pm 10$ ; Sway  $95.7 \pm 11$ ;  $p = 0.379$ ). ICC between K-D Balance scores was 0.71. Linear regression analysis demonstrated a significantly high correlation between the two balance devices ( $R^2 = 0.926$ ,  $p < 0.001$ ). Bland-Altman Plot showed majority of data points fall within 95% limits of agreement. **Conclusion:** K-D Balance and Sway Balance showed a statistically significant level of agreement, each providing objective measures of balance performance and allowing clinicians to both quantify balance performance and to monitor balance over time.

### Summary Points:

- ✓ Compared the agreement between K-D Balance versus Sway Balance, which are both objective balance assessments as mobile applications.
- ✓ There was a high level of correlation between the two balance tests.
- ✓ Utilizing quantitative balance measures will likely prove helpful in assessing and monitoring balance over time.



**Sports Neuropsychology  
Society**

Poster Presentation at the Sports Neuropsychology Society 2018 Annual Meeting

### **King-Devick and SCAT Symptoms as a Predictor of Return to Play in Professional Canadian Football Players**

Borza C, Mrazik M, Naidu D; *University of Alberta*

**Objective:** To investigate variables that predict time loss following the diagnosis of sport related concussion (SRC) in Canadian Football Players. **Background:** Literature on the timeline to return-to-play (RTP) from SRC remains largely mixed. The most consistent predictor of time loss post SRC is initial symptom report. CFL players have shown a clinically significant deficit on the K-D test post SRC. This study determined if symptoms report and the K-D test, a task of ocular motor function, would provide an indication of time to RTP. **Methods:** Subjects included 84 Canadian Football League



Players diagnosed with a SRC. The study design was quasi-experimental pretest-posttest. K-D Test and SCAT4/5 were completed at baseline and at the time of concussion during the 2015-2017 seasons. **Results:** Mean days lost due to concussion was 24.0 (SD=52); mean SCAT symptoms were 18.0 (SD=20.1); mean K-D test score difference was 3.7 seconds (SD=9.4). The time loss significantly correlated with the SCAT symptoms ( $p=0.034$ ) and K-D Test scores ( $p=0.02$ ). The regression analysis revealed a significant model with SCAT symptoms and K-D Test scores predicting time lost ( $r^2=0.077$ ,  $F(2,82) = 3.45$ , ( $p=0.037$ )). **Conclusion:** K-D difference scores and SCAT post injury scores may be an indicator of time loss in CFL players; however, the variance accounted by this formula was low (8%).

#### Summary Points:

- ✓ Ocular motor functioning, an area assessed by the K-D Test, has been suggested as a potential predictor of slow return-to-play.
- ✓ K-D Test scores and SCAT symptoms were significantly correlated with time loss (time away from play).
- ✓ Mean K-D Test difference pre- to post-concussion was 3.7 seconds for the Canadian Football League Players.
- ✓ K-D Test difference scores and SCAT post injury scores may be an indicator of time loss in CFL players.



**Sports Neuropsychology  
Society**

Poster Presentation at the Sports Neuropsychology Society 2018 Annual Meeting  
**Reliability of the King-Devick Test as a Baseline Concussion Test for Professional Football Players**

Schultz HM, Mrazik M, Naidu D; *University of Alberta*

**Objective:** To evaluate the reliability of the King-Devick (K-D) Test in a sample of professional football players across three consecutive seasons. **Methods:** Team personnel tested players ( $n=135$ ) with the K-D Test during pre-season medical evaluations for the seasons 2015- 2017. **Results:** Intraclass Correlation Coefficient (ICC) of 0.92 (95% CI = 0.89 to 0.94) suggests good reliability of K-D scores across three seasons. On average, athletes demonstrated significantly faster times between 2016 and 2015  $t(134) = -4.54$ ,  $p < 0.001$  ( $M = -2.14$ ,  $SD = 5.48$ ), between 2017 and 2016  $t(134) = -5.84$ ,  $p < 0.001$  ( $M = -1.93$ ,  $SD = 3.80$ ), and between 2017 and 2015  $t(134) = -8.09$ ,  $p < 0.001$  ( $M = -4.06$ ,  $SD = 5.83$ ).

**Conclusions:** The reliability of the K-D Test in a 3-year span of baseline assessment was classified as good. There were mild practice effects that continued into season three of the baseline assessments. To ensure optimal reliability of the K-D Test throughout an athlete's career, future research is needed to determine the frequency of baseline test administrations.

#### Summary Points:

- ✓ The King-Devick Test was shown to have good reliability over three seasons in professional Canadian Football Players ( $n=135$ ).
- ✓ K-D Test scores improved over each consecutive season, supporting the importance of establishing annual baseline tests pre-season for each athlete.



Poster Presentation at the American Academy of Neurology 2018 Annual Meeting

**Relation of Quantitative Eye Movements with Cognitive Dysfunction in Patients with Concussion**

Doria Gold1 , John Martone2 , Yuen Shan Christine Lee1 , Amanda Childs1 , Yuka Matsuzawa1 , Felicia Fraser1 , Joseph Ricker1 , Wei-Wei Dai2 , John-Ross Rizzo1 , Todd Hudson2 , Ivan Selesnick2 , Steven

Galetta1 , Laura Balcer2 , Janet Rucker1 *1 NYU Langone Medical Center, 2 NYU School of Medicine*

**Objective:** To assess the relation of quantitative eye movements with cognitive dysfunction in concussion. **Background:** Inter-saccadic interval (ISI) prolongation during rapid number naming on King-Devick (K-D) testing has been shown to underlie longer test times in patients with a history of concussion. The ISI is a measure of time between saccades, representing saccadic latency and fixation duration. Prolongation may result from increased saccade latency either as a result of, or in concert with, impaired attention and/or cognition. We sought to determine the relation of ISI prolongation and neuropsychological testing in a range of cognitive domains in concussion. **Design/Methods:** Analysis of sixteen patients with a concussion history (mean age  $41.7 \pm 13.6$  years, range 24- 65) who performed K-D with eye movement

recordings (EyeLink 1000+) and underwent neuropsychological testing. Primary neuropsychological measures included tests assessing effort, pre-morbid intellectual functioning, processing speed, attention and working memory, executive function, and mood as part of a concussion battery. Spearman rank-correlations were performed to examine the relation of ISI and neuropsychological measures. **Results:** Among 16 participants, aged 41.7 +/- 13.6 years, mean K-D test time was 72.6s +/-20.7; this is longer than the expected control value of 41.5s (prior studies). Mean ISI was 379.1msec +/-199.1. Greater ISI prolongation was associated with lower scores on measures of processing speed and attention/working memory: Trails Making Test Part A (rs=-0.64, P=0.009); Stroop Color Word (rs=-0.69, P=0.003); Digit Span Backward (rs =-0.59 P =0.02) and Digit Span Total (rs =-0.65 P =0.006). **Conclusions:** Results demonstrate associations between ISI prolongation and worse neuropsychological scores among patients with a history of concussion. Such deficits may reflect involvement of the dorsolateral prefrontal cortex (DLPFC) and subcortical structures in concussion, as these facilitate saccades, processing speed, and working memory. Ongoing studies will further refine cognitive function domains most associated with eye movement physiology in concussion.

#### Summary Points:

- ✓ K-D test and ISI times were prolonged in patients with a positive concussion history and were associated with lower cognitive scores
- ✓ These results may reflect associations between cognitive function domains and eye movement physiology in concussion.



#### Poster Presentation at the American Academy of Neurology 2018 Annual Meeting **‘Sandbagging’ a Vision Test for Concussion-based Sideline Assessment: An Eye Movement Investigation Objectively Reveals the ‘Gamers’ Strategies**

Janet Rucker<sup>1</sup>, Lisen Hasanaj<sup>1</sup>, John-Ross Rizzo<sup>1</sup>, Todd Hudson<sup>1</sup>, Weiwei Dai<sup>1</sup>, John Martone<sup>1</sup>, Yash Chaudhry<sup>1</sup>, Oluchi Ihionu<sup>1</sup>, Ivan Selesnick<sup>1</sup>, Laura Balcer<sup>2</sup>, Steven Galetta<sup>3</sup> <sup>1</sup> New York University, <sup>2</sup> NYU School of Medicine, <sup>3</sup> NYU Langone Medical Center

**Objective:** Quantitative eye movement characterization during ‘sandbagging’ of the rapid number naming King Devick (K-D) test. **Background:** Athletes may under-report concussion symptoms, leading to inappropriate return-to-play and increased risk of re-injury. Thus, attention has been directed toward tests to identify concussion, such as the K-D, for which longer test times compared to baseline are associated with concussion. There is concern that, in order to facilitate staying in the game in the event of concussion, athletes may attempt to prolong pre-season baseline testing times.

**Design/Methods:** Twenty-six healthy participants (mean age 29.1 +/- 7.6 years, range 20-59) with no concussion history performed K-D after reading a randomly selected cue card instructing them to intentionally prolong their reading time. Cards indicated that the examiner was blinded to this strategy. Twenty participants also performed K-D with standard instructions: to read as quickly as possible. Eye movements were recorded with videooculography (EyeLink 1000+).

**Results:** K-D testing times were substantially longer among participants whose scripts instructed them to ‘sandbag’ (91.6s vs 46.2s, p<0.001), as were inter-saccadic intervals (ISI) (413.9ms vs 273.2ms, p<0.01). Greater numbers of saccades (overall) (176.8 vs 140.5, p<0.01), as well as saccades in the wrong direction (reversed reading progression) (21.2% vs 10.8%, p<0.001), were generated during ‘sandbagging’. Saccade peak velocities and durations showed no differences between participants instructed to read the K-D as usual vs. sandbagging. **Conclusions:** K-D test ‘sandbagging’ results in eye movement behavior differences that are easily detectable by eye movement recordings and differentiable from prior reported findings in concussion. Specifically, ISI prolongation and greater numbers of saccades and reverse saccades occur with ‘sandbagging’. Such values detected on baseline assessment may suggest an invalid test score. Objective eye movement recording during KD performance shows promise for distinguishing between best effort and injury, as well as for identifying red flags on intentionally prolonged baseline performance.

#### Summary Points:

- ✓ K-D test ‘sandbagging’ results in eye movement behavior differences that are easily detectable by eye movement recordings and differentiable from prior reported findings in concussion.