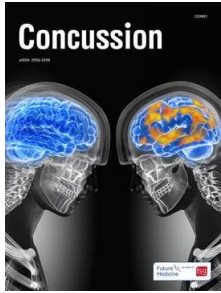


King-Devick Test for Concussion



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

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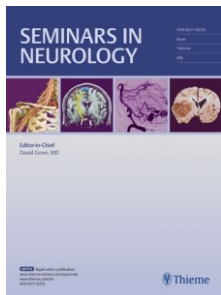
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Background: Vision encompasses a large component of the brain's pathways, yet is not represented in current sideline testing. **Objectives:** We performed a meta-analysis of published data for a vision-based test of rapid number naming (King-Devick [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.



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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.



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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 ($r=0.86$; $p<0.0001$). 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.



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

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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.

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

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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.

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

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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, 3rd 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 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 alternative between tablet and spiral versions of the K-D test



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

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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.



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.

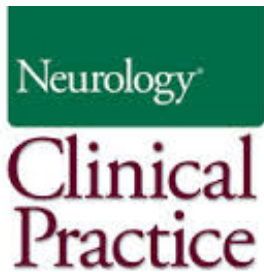
Summary Points:

- ✓ 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.



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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, 3rd 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 ≥ 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.



Neurology. 2011 Apr 26;76(17):1456-62.

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

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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 ± 7.4 vs 41.0 ± 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 ≥ 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



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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

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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.



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

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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 ± 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 ± 2.4 s) than unrecognised concussions (4.4 ± 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

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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.



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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

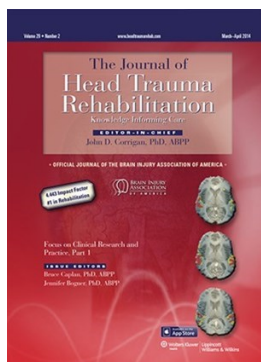
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The King-Devick (K-D) oculomotor test has recently been advocated for sideline diagnosis of concussion. Although, visual processing and performance are often impaired in concussion patients, the utility of K-D as a concussion diagnostic tool is not 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 ± 11.82 ; $\Delta V2-V3$: 9.17 ± 11.07 ; $\Delta V3-V4$: 5.30 ± 7.87 sec) and paralleled improvements in PCSS ($\Delta V1-V2$: 8.97 ± 20.27 ; $\Delta V2-V3$: 8.69 ± 14.70 ; $\Delta V3-V4$: 6.31 ± 7.71), RT ($\Delta V1-V2$: 0.05 ± 0.21 ; $\Delta V2-V3$: 0.09 ± 0.19 ; $\Delta V3-V4$: 0.03 ± 0.07) and VMS ($\Delta V1-V2$: -5.27 ± 6.98 ; $\Delta V2-V3$: -2.61 ± 6.48 ; $\Delta V3-V4$: -2.35 ± 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.



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

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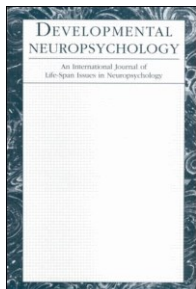
Objective: The purpose of this article is to synthesize and appraise the evidence regarding the use of oculomotor based vision assessment to identify and monitor recovery from mild traumatic brain injury (mTBI). Specific objectives are to (1) identify changes in oculomotor-based vision following mTBI; (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).



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.

SURGICAL NEUROLOGY INTERNATIONAL

Surgical Neurology International 2014

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.

Journal of Child Neurology

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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.



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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.

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.



J Neurol Sci. 2016. 10.1016/j.jns.2016.01.045

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

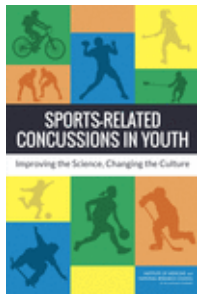
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Objective: Concussion is a major public health problem and considerable efforts are focused on sideline-based diagnostic testing to guide return-to-play decision-making and clinical care. The King-Devick (K-D) test, a sensitive sideline performance 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 (± 9.7) seconds. A total of 145 saccades (± 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 (± 10) and 17 (± 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.



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 (Galletta 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 ± 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 ± 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, Makdissi 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.



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

Sports-Related Concussion Testing

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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.



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 ± 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 ± 14.95 s, SP: 40.54 ± 15.92 s), while scores for HP signified slightly lower group means of 39.54 ± 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.



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

Gillian Hotz Ph.D, Ashlee Quintero, BSc, Ray Crittenden, MSc, Lauren Baker, David Goldstein and Kester Nedd, DO

United States Sports Academy

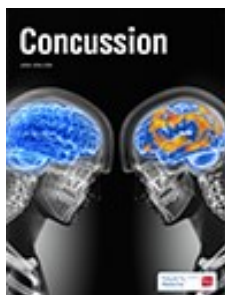
Background: With the national spotlight on concussions sustained in contact sports, this Countywide Concussion Program addresses the unique challenges presented to public and private high schools in order to increase concussion awareness, identification, and management. **Methods:** The Miami

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: the 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.



Concussion issued 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 ± 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.



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.¹ 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^{2,3} 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.⁴ 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.⁵ 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.⁵ 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 ± 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 ± 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 literature⁶, 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



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

Katharine S. Dempsey^{1,2}, Joel Birkemeier¹, John-Ross Rizzo¹, Lisena Hasanaj¹, Laura J. Balcer¹, Steven L. Galetta¹, Janet C. Rucker¹

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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 ± 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 North America 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 videooculographic (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 ± 15.4 sec vs. 42.8 ± 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 ± 116.9 msec vs. 317.7 ± 53.9 msec, $p=0.002$, t-test). The total number of saccades for ESL participants was significantly higher (149 ± 28 vs. 135 ± 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 North American Neuro-Ophthalmology Society North America 2016 Annual Meeting

Platform & Poster Presentation at the American Academy of Neurology 2016 Annual Meeting



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

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Introduction: 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 pre-season baseline. We determined the relation of rapid number naming time scores on the K-D test to video-oculographic eye movement performance during pre-season baseline assessments in a collegiate ice hockey team cohort. **Methods:** Athletes from collegiate ice hockey team received pre-season baseline testing as part of an ongoing study of rapid sideline/ rinkside 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 EyeLink 1000+. This allowed measurement of temporal and spatial characteristics of eye movements, including saccade velocity, duration and inter-saccadic intervals. **Results:** Among 13 male athletes, aged 18 to 23 years (mean 20.5±1.6 years), prolongation of the inter-saccadic interval (ISI, a combined measure of saccade latency and fixation duration) was the eye movement measure most associated with slower baseline KD scores (mean 38.2±6.2 seconds, $r=0.88$, $p=0.0001$). Older age was a predictor of longer (worse) K-D baseline time performance ($r=0.57$ - 0.70 , $p=0.008$ - 0.04) as well as prolonged ISI ($r=0.62$, $p=0.02$) in this collegiate cohort. Slower baseline K-D times were not associated with greater numbers of reported prior concussions. **Conclusions:** Rapid number naming performance at pre-season baseline is best correlated with ISI when eye movements are recorded. Baseline K-D scores notably worsened with increasing age but not with number of prior concussions in this small cohort. These findings suggest that duration of contact sport exposure, rather than concussion history, may influence pre-season baseline rapid number naming performance.

Summary Points:

- ✓ Laboratory-based eye movement study completed to determine eye movement performance during pre-season baseline assessments in collegiate ice hockey.
- ✓ Inter-saccadic intervals (ISI) represents a combined measure of saccade latency and fixation duration.
- ✓ Prolonged ISI was most associated with a slower baseline KD score.
- ✓ Older age was a predictor of longer KD baseline time performance and prolonged ISI.
- ✓ Slower baseline KD times were not associated with a greater number of reported prior concussions.

- ✓ Findings suggest that duration of contact sport exposure rather than concussion history may influence pre-season baseline KD performance.



Poster Presentation at the North American Neuro-Ophthalmology Society North America 2016 Annual Meeting

Platform & Poster Presentation at the American Academy of Neurology 2016 Annual Meeting



The Ocular Motor Underpinnings of Rapid Number-Naming as a Sideline Performance Measure for Concussion

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Introduction: The King-Devick (KD) test of rapid number-naming, a sensitive and rapid performance measure, adds a visual and eye movement outcome to sideline testing for concussion. We performed a laboratory-based study to characterize ocular motor behavior during the KD test in a cohort of patients with concussion to identify the features leading to KD reading time prolongation in concussion. **Methods:** We tested 12 subjects with a history of concussion (mean age 31) and compared their results to those of our normative database of non-concussed control participants (n=38, mean age 31). Participants performed a computerized version of the KD rapid number naming task. Simultaneous infrared-based video-oculographic recordings were performed using Eyelink 1000+, allowing measurement of temporal and spatial characteristics of eye movements (saccade velocity and duration, inter-saccadic interval, etc.). **Results:** Average inter-saccadic intervals (a combined measure of saccade latency and fixation duration) were significantly greater among concussed subjects compared to non-concussed controls (394.43 ± 140.64 msec vs. 312.45 ± 52.54 msec, $p=0.036$, t-test). Digitized KD reading times were prolonged in concussed participants versus non-concussed controls (52.43 ± 14.20 sec vs. 43.68 ± 8.54 sec, $p=0.032$, t-test). In addition to temporal differences, concussion was also associated with larger average deviations of horizontal saccade endpoints from the centers of to-be-read numbers (0.37 ± 0.35 deg vs. 0.13 ± 0.31 deg, $p=0.02$, t-test). There were no differences in saccade velocity, duration, amplitude, or in vertical deviation from number centers. **Conclusions:** Results of this study demonstrate that prolonged intersaccadic intervals and larger deviations of saccade endpoints likely underlie the increased reading times for the KD test in the setting of concussion. A sensitive and rapid sideline performance measure, the KD test of rapid number-naming relies upon a diffuse network responsible for saccade target selection and planning and captures deficits in efferent visual function characteristic of concussion.

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) 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.
- ✓ Concussion was associated with larger average deviations of horizontal saccade endpoints from the centers of to-be-read numbers.
- ✓ There were no differences in saccade velocity, duration, amplitude or vertical deviation from number centers.
- ✓ Prolonged ISI and larger deviations of saccade endpoints likely underlie the increased reading times for the K-D test in the setting of concussion.
- ✓ The K-D test of rapid number naming capture deficits in efferent visual function, characteristic of concussion.



Platform Presentation at the American Academy of Neurology 2014 Annual Meeting

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

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Objective: To evaluate the effects of head injury in adolescents on long-term cognitive and visuospatial performance and determine if similar impairment (subclinical concussion) exists in athletes without obvious head injury. **Background:** Sports concussion has an annual incidence of approximately 3.8 million. Over half go unreported and a substantial number may be asymptomatic. Repeat concussion is associated with serious consequences in long-term neurological function, to which adolescents may be more vulnerable. A rapid, cost-effective and reliable tool that facilitates diagnosis of concussion is needed. The King-Devick (K-D) test is a promising tool for real-time assessment of concussion. An increase in score from baseline suggests possible concussion. This is the first study to use K-D testing in adolescents for the detection of symptomatic and subclinical concussion. **Methods:** High school hockey players underwent K-D testing pre-season, post-season and immediately after suspected concussion. All were assessed pre- and post-season with a computerized cognitive assessment test (Axon Sports®). Additional testing was performed in a subgroup of non-concussed athletes before and after a game to determine impacts of fatigue and subconcussive hits on K-D scores. **Results:** 141 players were tested, of which 20 reported head injury. All 20 had immediate post-concussion K-D times >5s from baseline (average 7.3s) and all but 2 had worse post-season scores (46.4s vs. 52.4s $p<0.05$ Wilcoxon signed rank test). 11 non-concussed players had worse post-season times from baseline (37.6s vs. 43.8s). 110 players saw minimal improvement post-season (43.9s vs. 42.1s $p<0.05$) and 51 non-concussed players assessed before and after a game revealed no significant time change (43.4s vs. 42.0s post-game $p<0.05$). Pre- and post-season CCAT results will be correlated with K-D results and presented. **Conclusion:** King-Devick testing accurately identifies real-time, symptomatic concussion in adolescents. Scores in concussed players may remain abnormal over time. The K-D test may additionally detect asymptomatic concussion. Athletes should undergo pre- and post-season 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.



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

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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 ± 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 ± 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

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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 ≥ 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.



AMERICAN ACADEMY
of OPTOMETRY

Illinois College of Optometry, Chicago, IL

Paper Presentation at the AAO 2014 Annual Meeting

King-Devick Test-Retest Reliability among Youth during AAU Junior Olympic Games

Valeriya Smolyansky, Stephen Beckerman

Objective: There has been considerable research to determine the relationship between visual skills and athletic performance. It has been suggested that if athletes can improve the elements of their visual system, they can elevate their athletic performance. Additionally, 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 reliable screening test of rapid number naming that requires eye movements, language, attention and concentration to complete. K-D Test has been validated as a measure to determine concussion by identifying suboptimal brain function. The purpose of this investigation is to determine the potential effects

of age on K-D scores and determine the test-retest reliability of the King Devick test in elite youth athletes. **Methods:** 54 athletes (mean age 11.7, range 6-17 years) participating in the AAU Junior Olympic Games in Detroit, Michigan 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 is an accurate and reliable test for young athletes that can be implemented into vision screenings to guide vision training enhancement of athletic performance and as a reliable tool to reveal suboptimal brain function as a result of concussion in youth. These findings also underscore the importance of measuring pre-season K-D concussion baseline scores, especially in young athletes.

Summary Points:

- ✓ There was high test-retest reliability between K-D test administrations in Junior Olympic athletes.
- ✓ Faster K-D scores were observed with older athletes compared with younger athletes.
- ✓ The K-D test is accurate and reliable for young athletes with up-to-date baseline scores.



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.

King-Devick for Neurological Function



Alzheimer Dis Assoc Disord 2016;00:000-000

Screening Utility of the King-Devick Test in Mild Cognitive Impairment and Alzheimer Disease Dementia

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The King-Devick (K-D) test is a 1 to 2 minute, rapid number naming test, often used to assist with detection of concussion, but also has clinical utility in other neurological conditions (eg, Parkinson disease). The K-D involves saccadic eye and other eye movements, and abnormalities thereof may be an early indicator of Alzheimer disease (AD)-associated cognitive impairment. No study has tested the utility of the K-D in AD and we sought to do so. The sample included 206 [135 controls, 39 mild cognitive impairment (MCI), and 32 AD dementia] consecutive subjects from the Boston University Alzheimer's Disease Center registry undergoing their initial annual evaluation between March 2013 and July 2015. The K-D was administered during this period. Areas under the receiver operating characteristic curves generated from logistic regression models revealed the K-D test distinguished controls from subjects with cognitive impairment (MCI and AD dementia) [area under the curve (AUC)=0.72], MCI (AUC=0.71) and AD dementia (AUC=0.74). K-D time scores between 48 and 52 seconds were associated with high sensitivity (>90.0%) and negative predictive values (>85.0%) for each diagnostic group. The K-D correlated strongly with validated attention, processing speed, and visual scanning tests. The K-D test may be a rapid and simple effective screening tool to detect cognitive impairment associated with AD.

Summary Points:

- ✓ Current estimates indicate 5.3 million Americans are living with AD and the prevalence is expected to rise exponentially over the next 2 decades.
- ✓ A brief, non-invasive test that is rapid and easy to administer, and is sensitive to detection of MCI and AD dementia would be optimal for primary care or similar settings.
- ✓ Saccadic eye movement impairments are one of the most commonly documented forms of oculomotor dysfunction in AD patients.
- ✓ The objective of this study was to examine the utility and accuracy of the K-D in a sample of cognitively healthy older adult controls, and individuals with MCI and AD dementia from the Boston University Alzheimer's Disease Center participant registry.
- ✓ The study revealed significant differences on the K-D total time score across the diagnostic groups as well as total errors. Both MCI and AD dementia subjects performed worse than controls on the K-D.
- ✓ The K-D was an effective measure for identifying cognitive impairment and distinguishing between patients with MCI and AD dementia from healthy older adults.
- ✓ The K-D performed equally well in detecting MCI and AD dementia from controls and therefore supports its utility in the detection of subtle cognitive impairment, and its application is not limited to severe forms of cognitive impairment.
- ✓ The K-D Test evaluates processing speed and visual tracking and performance on the test is dependent on saccadic eye movement.
- ✓ The K-D is an ideal test for many clinicians and clinical researchers in high patient and research subject volume settings.
- ✓ In addition to being brief and inexpensive, the K-D test requires minimal training to administer or interpret.

- ✓ The K-D was highly correlated with other well-established and validated neuropsychological measures of attention, visual tracking, and processing speed. Given that these measures assess mental abilities that overlap with those required for the K-D, the study provides evidence for good convergent validity for the K-D Test.
- ✓ The accuracy of the well-validated neuropsychological tests in detecting cognitive impairment improved in the presence of the K-D, highlighting the additive clinical utility of this measure.
- ✓ The K-D is a brief and easily administered test that may be an effective tool to detect cognitive impairment. Findings suggest that the K-D may be an appropriate screening measure in fast-paced clinical settings, such as primary care offices, to assist in the early detection of cognitive impairment and guide referral for more comprehensive evaluation to ultimately facilitate early intervention.



Parkinsonism & Related Disorders. 2014;20(2):226-9.

Slowing of Number Naming Speed by King-Devick Test in Parkinson's Disease

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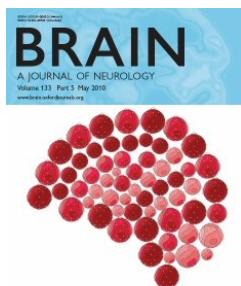
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BACKGROUND: The King-Devick (KD) test measures the speed of rapid number naming, and is postulated to require fast eye movements, attention, language, and possibly other aspects of cognitive functions. While used in multiple sports concussion studies, it has not been applied to the field of movement disorders. **METHODS:** Forty-five Parkinson's disease (PD), 23 essential tremor (ET), and 65 control subjects were studied. Subjects performed two trials of reading out loud single-digit numbers separated by varying spacing on three test cards that were of different formats. The sum time of the faster trial was designated the KD score and compared across the three groups. **RESULTS:** PD patients had higher (worse) KD scores, with longer reading times compared to ET and control subjects (66 seconds vs. 49 sec. vs. 52 sec., $p < 0.001$, adjusting for age and gender). No significant difference was found between ET and control ($\Delta = -3$ seconds, 95% CI: -10 to 4). **CONCLUSIONS:** This is the first study of the King-Devick Test in Parkinson's disease. PD patients were found to have a slower rapid number naming speed compared to controls. This test may be a simple and rapid bedside tool for quantifying correlates of visual and cognitive function in Parkinson's disease.

Summary Points:

- ✓ Two trials of the K-D Test was administered to individuals with Parkinson's Disease (PD) and essential tremor (ET) and compared with controls.
- ✓ Those with PD scored significantly worse on the K-D Test compared to those with ET and the control group (adjusting for age and gender).
- ✓ There was no significant difference in scores in the ET group versus control group.
- ✓ The K-D Test may be an effective bedside tool for quantifying aspects of visual and cognitive function in patients with PD.



Brain. 2014;138(1):11-27.

Vision and vision-related outcome measures in multiple sclerosis

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Visual impairment is a key manifestation of multiple sclerosis. Acute optic neuritis is a common, often presenting manifestation, but visual deficits and structural loss of retinal axonal and neuronal integrity can occur even without a history of optic neuritis. Interest in vision in multiple sclerosis is growing, partially in response to the development of sensitive visual function tests, structural markers such as optical coherence tomography and magnetic resonance imaging, and quality of life measures that give clinical meaning to the structure-function correlations that are unique to the afferent visual pathway. Abnormal eye movements also are common in multiple sclerosis, but quantitative assessment methods that can be applied in practice and clinical trials are not readily available. We summarize here a

comprehensive literature search and the discussion at a recent international meeting of investigators involved in the development and study of visual outcomes in multiple sclerosis, which had, as its overriding goals, to review the state of the field and identify areas for future research. We review data and principles to help us understand the importance of vision as a model for outcomes assessment in clinical practice and therapeutic trials in multiple sclerosis.

"The King-Devick Test, a brief rapid number-naming test new to the multiple sclerosis field, is a potential quantitative bedside performance measure of efferent visual dysfunction (Moster et al., 2014). This test takes 2 min to complete and is sensitive to dysfunction of saccadic and other eye movements; time scores are higher (worse) among patients with multiple sclerosis compared to disease-free controls. Further studies of this and other efferent visual function tests in multiple sclerosis are needed to bring assessment of this aspect of vision to the level of afferent system investigation."

Summary Points:

- ✓ Review of literature exploring clinical measures of vision for patients with MS.
- ✓ Abnormalities of ocular motility are common in MS.
- ✓ The K-D Test is sensitive to saccadic dysfunction and other eye movements.
- ✓ K-D scores are worse among patients with MS compared to disease-free controls.



J Neurol Sci. 2014;343(1-2):105-109.

The King-Devick (K-D) Test of Rapid Eye Movements: A Bedside Correlate of Disability and Quality of Life in MS

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OBJECTIVE: We investigated the King-Devick (K-D) test of rapid number naming as a visual performance measure in a cohort of patients with multiple sclerosis (MS). **METHODS:** In this cross-sectional study, 81 patients with MS and 20 disease-free controls from an ongoing study of visual outcomes underwent K-D testing. A test of rapid number naming, K-D requires saccadic eye movements as well as intact vision, attention and concentration. To perform the K-D test, participants are asked to read numbers aloud as quickly as possible from three test cards; the sum of the three test card times in seconds constitutes the summary score. High-contrast visual acuity (VA), low-contrast letter acuity (1.25% and 2.5% levels), retinal nerve fiber layer (RNFL) thickness by optical coherence tomography (OCT), MS Functional Composite (MSFC) and vision-specific quality of life (QOL) measures (25-Item NEI Visual Functioning Questionnaire [NEI-VFQ-25] and 10-Item Neuro-Ophthalmic Supplement) were also assessed. **RESULTS:** K-D time scores in the MS cohort (total time to read the three test cards) were significantly higher (worse) compared to those for disease-free controls ($P = 0.003$, linear regression, accounting for age). Within the MS cohort, higher K-D scores were associated with worse scores for the NEI-VFQ-25 composite ($P < 0.001$), 10-Item Neuro-Ophthalmic Supplement ($P < 0.001$), binocular low-contrast acuity (2.5%, 1.25%, $P < 0.001$, and high-contrast VA ($P = 0.003$). Monocular low-contrast vision scores ($P = 0.001$ -0.009) and RNFL thickness ($P = 0.001$) were also reduced in eyes of patients with worse K-D scores (GEE models accounting for age and within-patient, inter-eye correlations). Patients with a history of optic neuritis (ON) had increased (worse) K-D scores. Patients who classified their work disability status as disabled (receiving disability pension) did worse on K-D testing compared to those working full-time ($P = 0.001$, accounting for age). **CONCLUSIONS:** The K-D test, a < 2 minute bedside test of rapid number naming, is associated with visual dysfunction, neurologic impairment, and reduced vision-specific QOL in patients with MS. Scores reflect work disability as well as structural changes as measured by OCT imaging. History of ON and abnormal binocular acuities were associated with worse K-D scores, suggesting that abnormalities detected by K-D may go along with afferent dysfunction in MS patients. A brief test that requires saccadic eye movements, K-D should be considered for future MS trials as a rapid visual performance measure.

Summary Points:

- ✓ The K-D Test captures visual dysfunction, vision specific quality of life and neurology impairment in MS.
- ✓ K-D scores correlated with work disability and retinal structural changes.
- ✓ History of optic neuritis and abnormal binocular visual acuity, common ocular complications of MS, were associated with worse K-D scores.
- ✓ Findings support the K-D Test as a rapid visual performance measure for MS trials.



Neurology. 2012; 78:e103-e106.

Residency Training: The King-Devick Test and sleep deprivation: Study in pre- and post-call neurology residents

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OBJECTIVE: The current study investigates the effect of sleep deprivation on the speed and accuracy of eye movements as measured by the King-Devick (K-D) test, a 1-minute test that involves rapid number naming. **METHODS:** In this cohort study, neurology residents and staff from the University of Pennsylvania Health System underwent baseline followed by post-call K-D testing ($n = 25$); those not taking call ($n = 10$) also completed baseline and follow-up K-D testing. Differences in the times and errors between baseline and follow-up K-D scores were compared between the 2 groups. **RESULTS:** Residents taking call had less improvement from baseline K-D times when compared to participants not taking call ($p < 0.0001$, Wilcoxon rank sum test). For both groups, the change in K-D time from baseline was correlated to amount of sleep obtained ($r_s = -0.50$, $p = 0.002$) and subjective evaluation of level of alertness ($r_s = 0.33$, $p = 0.05$) but had no correlation to time since last caffeine consumption ($r_s = -0.13$, $p = 0.52$). For those residents on their actual call night, the duration of sleep obtained did not correlate with change in K-D scores from baseline ($r_s = 0.13$, $p = 0.54$). **CONCLUSIONS:** The K-D test is sensitive to the effects of sleep deprivation on cognitive functioning, including rapid eye movements, concentration, and language function. As with other measures of sleep deprivation, K-D performance demonstrated significant inter-individual variability in vulnerability to sleep deprivation. Severe fatigue appears to reduce the degree of improvement typically observed in K-D testing.

Summary Points:

- ✓ Neurology residents underwent baseline K–D testing followed by post call K–D testing.
- ✓ Post-call residents had less improvement from baseline K-D score compared to those who were not taking call.
- ✓ Changes in K-D times from baseline were correlated to amount of sleep obtained (less sleep associated with less improvement in K-D score).
- ✓ The study concluded that the K–D test is sensitive to the effects of severe sleep deprivation on cognitive functioning, including rapid eye movements, concentration, and language function.



Aviat Space Environ Med. 2014; 85:700-7.

Acute Hypoxic Hypoxia and Isocapnic Hypoxia Effects on Oculometric Features

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INTRODUCTION: Visual performance impairment after hypoxia is well recognized in military and civilian aviation. The aims of this study were: 1) to assess oculometric features such as blink metrics, pupillary dynamics, fixations, and saccades as cognitive indicators of early signs of hypoxia; and 2) to analyze the impact of different hypoxic conditions [“hypoxic hypoxia” (HH) and “isocapnic hypoxia” (IH)] on specified oculometrics during mental workloads. **METHODS:** Oculometric data were collected on 25 subjects under 3 conditions: normoxia, HH (8% O₂ + balance N₂), and IH (7% O₂ + 5% CO₂ + balance N₂). The mental workload task consisted of reading aloud linear arrays of numbers after exposure to gas mixtures. **RESULTS:** Blink rates were significantly increased under hypoxic conditions (by +100.7% in HH and by +92.8% in IH compared to normoxia). A faster recovery of blink rate was observed in transitioning from IH (23.6% vs. 76.3%) to normoxia. The percentage change in pupil size fluctuation was increased under HH more than under IH (29% vs. 4.4%). Under HH average fixation time and target area size were significantly higher than under IH. Total saccadic times under hypoxic conditions were significantly increased compared with normoxia. **CONCLUSIONS:** These results suggest that oculometric changes are indicators of hypoxia, which can be monitored using compact, portable, noninvasive eye-tracking devices in a cockpit analogous environment to detect hypoxia-induced physiological changes in aircrew. Comparative results between HH and IH support the potential role of carbon dioxide in augmenting cerebral perfusion and hence improved tissue oxygen delivery.

Summary Points:

- ✓ Investigated oculometric tests as cognitive indicators of early signs of hypoxia.
- ✓ Blink rates increased, pupil size fluctuations increased, higher fixation time and target area size, and worse King-Devick Test scores were measured under hypoxic conditions (HH 8% O₂ + balance N₂) versus normoxia.
- ✓ The K-D Test measures saccadic function, which may be a reliable marker in neuro-physiological changes induced by hypoxia, and useful in assessing early signs of hypoxia prior to cognitive impairment.



Aviat Space Environ Med. 2013; 84:1017-22.

Early Detection of Hypoxia-Induced Cognitive Impairment Using the King-Devick Test

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INTRODUCTION: Hypoxic incapacitation continues to be a significant threat to safety and operations at high altitude. Noninvasive neurocognitive performance testing is desirable to identify pre-symptomatic cognitive impairment, affording operators at altitude a tool to quantify their performance and safety. **METHODS:** There were 25 subjects enrolled in this study. Cognitive performance was assessed by using the King-Devick (K-D) test. The performance of the subjects on the K-D test was measured in normoxia followed by hypoxia (8% O₂ equivalent to 7101 m) and then again in normoxia. **RESULTS:** K-D test completion time in hypoxia for 3 min was significantly longer than the Baseline Test (54.5 ± 12.4 s hypoxic vs. 46.3 ± 10.4 s baseline). Upon returning to normoxia the completion time was significantly shorter than in hypoxia (47.6 ± 10.6 s post-test vs. 54.5 ± 12.4 s hypoxic). There was no statistically significant difference between baseline test and post-test times, indicating that all subjects returned to their normoxic baseline levels. S_pO₂ decreased from $98 \pm 0.9\%$ to $80 \pm 7.8\%$ after 3 min on hypoxic gas. During the hypoxic K-D test, S_pO₂ decreased further to $75.8 \pm 8.3\%$. **CONCLUSIONS:** In this study the K-D test has been shown to be an effective neurocognitive test to detect hypoxic impairment at early pre-symptomatic stages. The K-D test may also be used to afford a reassessment of traditional measures used to determine hypoxic reserve time.

Summary Points:

- ✓ The performance of 25 subjects on the K-D test was measured in normoxic conditions followed by hypoxic conditions (8% O₂ equivalent to 7101 m altitude) and then again in normoxia.
- ✓ K-D test time after exposure to 3 minutes of hypoxia was significantly longer than baseline.
- ✓ After returning to normoxia, the K-D time was significantly improved compared to hypoxic performance.
- ✓ There was no statistically significant difference between baseline test and post-test times.
- ✓ The K-D test may be used to detect hypoxia at early pre-symptomatic stages.



Swedish Radiation Safety Authority. 2015:20
<http://www.stralsakerhetsmyndigheten.se>

The Effects of Mild, Acute Hypoxia on Cognitive Performance

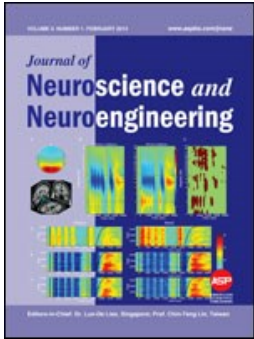
Martin Castor, Jonathan Borgvall; GEIST AB, Kista

BACKGROUND: The Swedish nuclear power plant Forsmarks Kraftgrupp AB (FKA) reported that they wanted to use a fire prevention method by reducing the oxygen level down to 15% in some locations. The personnel are only going to work there for a limited number of hours. This fire protection method has never been used before in any nuclear power plant in spaces where people work. The background to the study was the lack of comparable, sufficiently relevant scientific literature on the topic of whether cognitive ability deteriorates or not when the oxygen (O₂) level is reduced from the normal level (21%) to 15%, without habituation. SSM needed more knowledge of whether the cognitive abilities of the personnel could be affected in a negative way. The goal of the study was to provide SSM with the basis for oversight. **OBJECTIVES:** The study was divided into two parts, a literature study and an experimental part. The phenomenon studied was comparable to the situation at the nuclear power plant. The persons involved in the experimental phase were exposed to a change from normal oxygen level to a reduced oxygen level without having time to adapt. The exposure to 15% oxygen was 2 h during the first exposure, 2 h during the second exposure and 45 min during the third and final exposure. **RESULTS:** The literature review primarily identified evidence that the effects on cognitive performance due to hypoxia at 15% O₂, if any, would be small. A few researchers have reported findings that support

adverse effects on cognitive performance already at 16-15% O₂ concentration. In support of the hypothesis that no adverse effects on cognitive performance could be observed under conditions studied, there were no significant decreases in cognitive performance as a result of exposure to the experimental conditions with 15% O₂. This study was clearly delineated and several possible influencing aspects were not included. Therefore, we cannot rule out possible interaction effects, with negative impact on cognitive ability, between hypoxia and other factors such as diseases, medication and drugs, concussion history, or other aspects of air quality.

Summary Points:

- ✓ There were no statistically significant differences in performance on the K-D test across baseline (normal room air) and the three exposures to the experimental condition (nitrogen-balanced breathing gas mixture of 15% O₂).
- ✓ K-D test results across the total of 16 test occasions showed the largest performance change occurring between the first and second test occasion.



J Neurosci Neuroeng. 2014; 3(1): 1-11.

Assessment of Prefrontal Cortex Activity in Amyotrophic Lateral Sclerosis Patients with Functional Near Infrared Spectroscopy

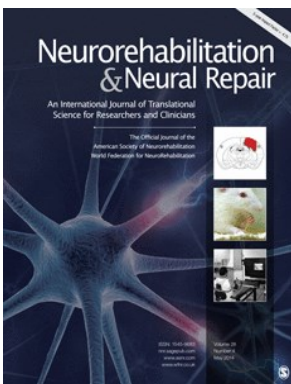
Hasan Ayaz¹ *, Patricia A. Shewokis^{1,2}, Lauren Scull³, David J. Libon³, Sara Feldman³, Joel Eppig³, Banu Onaral¹, and Terry Heiman-Patterson³

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Cognitive impairment in amyotrophic lateral sclerosis (ALS) is associated with cortical changes beyond the motor cortex. The overall goal of this project is to determine if task induced hemodynamic changes detected by functional near infrared (fNIR) spectroscopy from the anterior prefrontal cortex (PFC) has discriminant validity across ALS (n = 17) patients and matching healthy (n = 17) controls. The experimental protocol was composed of the King-Devick Test, the Number Interference Test and a Continuous Performance Test targeting a range of cognitive domains including sustained attention and executive function. Results indicate that fNIR measures provided significant differences between ALS and healthy controls in all three tasks providing an additional metric for the assessment of cognitive decline. Although this is a pilot study, given the safe, wearable and real world validity of fNIR, these results may set the foundation for the use of fNIR as a clinical tool in monitoring progression of neurocognitive decline in a simple, less invasive and objective manner than allowed by current imaging technology.

Summary Points:

- ✓ Researchers utilized the King-Devick Test as a measure for evaluating the significance of functional near infrared spectroscopy of the brain for patients with ALS.
- ✓ K-D Test scores were significantly worse in the ALS group versus controls.
- ✓ The K-D Test captures impairment of eye movements, attention, language, and other correlates of suboptimal brain function in ALS.



Neurorehabil Neural Repair. 2014 Nov-Dec;28(9):856-73.

The Effect of Visual Scanning Exercises Integrated Into Physiotherapy in Patients with Unilateral Spatial Neglect Poststroke: A Matched-Pair Randomized Control Trial

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University of Pretoria, Pretoria, South Africa

Background: Unilateral spatial neglect (USN) is a visual-perceptual disorder that entails the inability to perceive and integrate stimuli on one side of the body, resulting in the neglect of one side of the body. Stroke patients with USN present with extensive functional disability and duration of therapy input. **Objective:** To determine the effect of saccadic eye movement training with visual scanning exercises (VSEs) integrated with task-specific activities on USN poststroke. **Methods:** A

matched-pair randomized control trial was conducted. Subjects were matched according to their functional activity level and allocated to either a control (n = 12) or an experimental group (n = 12). All patients received task-specific activities for a 4-week intervention period. The experimental group received saccadic eye movement training with VSE integrated with task specific activities as an “add on” intervention. Assessments were conducted weekly over the intervention period. **Results:** Statistical significant difference was noted on the King-Devick Test (P = .021), Star Cancellation Test (P = .016), and Barthel Index (P = .004). **Conclusion:** Intensive saccadic eye movement training with VSE integrated with task-specific activities has a significant effect on USN in patients poststroke. Results of this study are supported by findings from previously reviewed literature in the sense that the effect of saccadic eye movement training with VSE as an intervention approach has a significant effect on the visual perceptual processing of participants with USN poststroke. The significant improved visual perceptual processing translate to significantly better visual function and ability to perform activities of daily living following the stroke.

Summary Points:

- ✓ Post-stroke patients with visual-perceptual dysfunction underwent 4 weeks of visual scanning exercises.
- ✓ The King-Devick Test was used to evaluate saccadic eye movement function pre- and post-training.
- ✓ There was a significant difference in K-D Test scores following training.
- ✓ The K-D Test is a useful clinical tool in monitoring progress in patients with visual difficulties following a stroke.



J Parkinsons Dis. 2015;5(1):125-130.

Abnormal Visual Contrast Acuity in Parkinson's Disease

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Background: Low-contrast vision is thought to be reduced in Parkinson's disease (PD). This may have a direct impact on quality of life such as driving, using tools, finding objects, and mobility in low-light condition. Low-contrast letter acuity testing has been successful in assessing low-contrast vision in multiple sclerosis. We report the use of a new iPad application to measure low-contrast acuity in patients with PD. **Objective:** To evaluate low- and high-contrast letter acuity in PD patients and controls using a variable contrast acuity eye chart developed for the Apple iPad. **Methods:** Thirty-two PD and 71 control subjects were studied. Subjects viewed the Variable Contrast Acuity Chart on an iPad with both eyes open at two distances (40 cm and 2m) and at high contrast (black and white visual acuity) and 2.5% low contrast. Acuity scores for the two groups were compared. **Results:** PD patients had significantly lower scores (indicating worse vision) for 2.5% low contrast at both distances and for high contrast at 2m ($p < 0.003$) compared to controls. No significant difference was found between the two groups for high contrast at 40 cm ($p = 0.12$). **Conclusions:** Parkinson's disease patients have reduced low and high contrast acuity compared to controls. An iPad app, as used in this study, could serve as a quick screening tool to complement more formal testing of patients with PD and other neurologic disorders.

Summary Points:

- ✓ High contrast and low contrast visual acuity was measured in individuals with Parkinson's Disease (PD) and compared to controls.
- ✓ Contrast acuity was measured with the King-Devick Variable Contrast Acuity Chart as an application on an iPad.
- ✓ PD patients had significantly worse low contrast visual acuity (2.5% at 40 cm and 2 m) and worse high contrast acuity at far (100% at 2 m), compared to those without PD.
- ✓ Low contrast acuity scores correlated with disease severity.
- ✓ The K-D Variable Contrast Acuity Chart provides a portable, adjustable, quantitative measure of contrast visual acuity, and may reveal undiagnosed visual impairment in patients with PD, along with a use in monitoring PD severity.



Poster Presentation at the North American Neuro-Ophthalmology Society North America 2016 Annual Meeting

Capturing the Efferent Side of Vision in Multiple Sclerosis: New Data from a Digitized Rapid Number Naming Task

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Introduction: Visual function in multiple sclerosis (MS) has been well characterized from an afferent standpoint using low-contrast acuity, optical coherence tomography (OCT) and quality of life (QOL). Compared to controls, patients with MS also demonstrate slowed reading times on the King-Devick (K-D) test, a rapid number naming task that captures widely distributed aspects of efferent function, particularly saccades. Slowed times in MS are associated with neurologic dysfunction and reduced vision-specific (QOL). However, the ocular motor underpinnings of such slowing have not been determined. We sought to determine ocular motor performance and characterize deficits leading to slowed KD reading times using recorded eye movements during a digitized King-Devick (K-D) test. **Methods:** We tested 13 patients with MS (mean age 37) and compared their results to those of our normative database of control participants without MS (n=38, mean age 31). Participants completed the digitized K-D task with simultaneous video-oculographic eye movement recording (EyeLink 1000+). Data were analyzed off-line in Matlab and Stata 14.0. **Results:** Digitized K-D completion times in the MS cohort were longer (worse) relative to controls (52.6 ± 14.1 sec vs. 43.7 ± 8.5 sec, $p=0.02$, ttest). Intersaccadic intervals (ISI), which represent a combination of saccadic latency and fixation duration between saccades, were prolonged in MS patients (397 ± 137 msec vs. 312 ± 53 msec, $p=0.02$, t-test). Within the MS cohort, test times were longer for the digitized vs. spiral-bound hand-held K-D test (52.0 ± 9.2 sec vs. 43.7 ± 9.7 sec, $p=0.01$, linear regression).

Conclusions: In this ongoing study of ocular motor performance in MS, we have demonstrated that K-D reading times are slower secondary to prolonged ISI. The K-D test captures efferent visual dysfunction in MS, and is likely to be a sensitive performance-based outcome measure for future research, practice and clinical trials.

Summary Points:

- ✓ Laboratory-based eye movement study completed to determine oculomotor performance and characterize KD deficits in multiple sclerosis (MS).
- ✓ Digitized KR reading times were prolonged for MS patients compared to controls.
- ✓ Average inter-saccadic intervals (ISI) represents a combined measure of saccade latency and fixation duration.
- ✓ ISI was prolonged in MS patients.
- ✓ The K-D test captures efferent visual dysfunction in MS as such is a sensitive performance-based outcome measure for future research, practice, and clinical trials.



Poster Presentation at American Academy of Neurology 2015 Annual Meeting

Visual Performance Testing in Children with Attention Deficit Hyperactivity Disorder

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BACKGROUND: ADHD is the most prevalent pediatric neurodevelopment disorder. In the United States, it is estimated that 5.4 million children 6 and 17 years of age (or 9.5% of U.S. children) have received an ADHD diagnosis. The King-Devick (K-D) test is a vision-based test of rapid number naming that requires saccades and visual processing. In sideline studies of youth and collegiate athletes with concussion, the K-D test consistently demonstrates higher (worse) time scores post-injury compared to pre-season baseline scores. There is growing evidence that, like concussion and mild traumatic brain injury, ADHD may be associated with visual pathway dysfunction. **PURPOSE:** Using the King-Devick (K-D) test, a vision-based test of rapid number naming that requires saccades and visual processing. We investigated whether children with ADHD has worse scores compared to similar aged controls. **METHODS:** Design: Prospective study of children with ADHD (diagnosed by Conners Scale and NYU pediatric neurologist) and age-matched controls. Participants: Patients diagnosed with ADHD (5-21 years of age) seeking care from the NYU Neurology Faculty Group

Practice and Child Study Center. Analyses compared K-D scores of patients with ADHD to those of pre-season baseline scores for student-athletes controls category matched for age and gender. King-Devick Test: a vision-based measure of rapid number naming that varies the spacing between numbers on successive cards. **RESULTS:** Among 134 participants in this study, ADHD vs. control status was significantly associated with higher K-D test time scores ($p < 0.001$, logistic regression models, accounting for age). K-D showed a greater capacity to distinguish ADHD vs. control groups in youths older than 11 years of age (ROC curve areas from logistic regression models was, 0.55 for youths ≤ 11 years of age and 0.79 for youths ≥ 11 years of age). Patients with ADHD took an average of 14 seconds longer to complete the K-D test, compared to control youth ($p < 0.001$, two-sample t-test). Use of stimulant medications was not associated with differences in K-D time scores within the cohort of patients with ADHD ($p > 0.05$, best KD trial of ADHD on Rx vs. best KD trial of ADHD off Rx). **CONCLUSIONS:** Visual pathways may perform or be utilized differently in youths with ADHD compared to controls. This alteration in visual performance on the K-D test in youths with ADHD is likely due to the widespread distribution of brain pathways devoted to vision (approximately 50% of the brain's circuits). The limited capacity of the K-D to distinguish ADHD in youths younger than 11 years of age may be due to variations in reading ability in this age group. Use of stimulant medication was not associated with altered K-D test performance.

Summary Points:

- ✓ Investigated if there was a difference in the King-Devick Test of rapid number naming in subjects (ages 5-21) with ADHD versus those without.
- ✓ Subjects with ADHD showed significantly worse K-D scores compared to the controls.
- ✓ The K-D Test demonstrated a greater capacity to distinguish ADHD vs. control groups in youths older than 11 years of age (ROC curve areas from logistic regression models was, 0.55 for youths ≤ 11 years of age and 0.79 for youths ≥ 11 years of age).
- ✓ Patients with ADHD took an average of 14 seconds longer to complete the K-D test, compared to control youth ($p < 0.001$, two-sample t-test).
- ✓ ADHD medication was not associated with differences in K-D scores within the cohort.
- ✓ Since ADHD is a neuro-development disorder and more than 50% of the brain is devoted to vision, the K-D Test highlights aspects of vision which may be affected by ADHD.



Poster Presentation at American Academy of Neurology 2015 Annual Meeting

Validation of Strategies to Streamline High and Low Contrast Acuity testing in ALS Subjects

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BACKGROUND: Afferent visual system disorders are included in the phenotypic spectrum Amyotrophic Lateral Sclerosis (ALS). High and low contrast visual acuity (HCVA and LCVA) are potential quantitative clinical markers of this dysfunction. Gold standard clinical research protocols for HCVA and LCVA measurements are difficult to implement in a neurology clinic. Pinhole is a possible substitute for refraction, which is time consuming requiring specialized equipment and personnel. Charts presented on tablets are a potential substitute for retro-illuminated charts, which are bulky and less readily available. The purpose of this study is to evaluate the effect of substituting pinhole for refraction and tablet charts for retro-illuminated charts on HCVA and LCVA in ALS patients. **DESIGN/METHODS:** Monocular HCVA and 2.5% LCVA were measured at 2m in 8 ALS subjects using two chart conditions (retro-illuminated Sloan charts, iPad presented charts) and two correction conditions (spherical refraction, pinhole). Number of letters correctly identified was compared between chart condition and between correction conditions. Differences less than 5 letters (1 line) were considered comparable. **RESULTS:** HCVA was comparable between correction conditions and between chart conditions for 6/8 (75%) and 7/8 (88%) subjects respectively. LCVA was comparable between correction conditions and between chart conditions for 3/8 (38%) and 6/8 (75%) respectively. In comparable values favored pinhole for HCVA and spherical refraction for LCVA. **CONCLUSIONS:** In this pilot study, we find that HCVA and LCVA tablet presented charts produce comparable measurements to gold standard retro-illuminated charts in greater than 75% of ALS subjects. Pinhole correction is comparable to spherical refraction for measurements of HCVA but not LCVA. HCVA measurements with pinhole and tablet charts are less burdensome for ALS patients and research staff without sacrificing accuracy. Pinhole is not a suitable modification for LCVA measurements.

Summary Points:

- ✓ Compared the King-Devick Contrast Acuity Chart to the retro-illuminated Sloan chart in patients with ALS.
- ✓ High and low contrast visual acuity was comparable between the two chart types.
- ✓ The K-D Contrast Acuity Chart demonstrated an accurate measurement of contrast acuity, with the benefit of both portability, illumination, and availability compared to retro-illuminated charts.

King-Devick Reading Acceleration Program



The Effect of In-School Saccadic Training on Reading Fluency and Comprehension in First and Second Grade Students: A Randomized Controlled Trial

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Efficient eye movements provide a physical foundation for proficient reading skills. We investigated the effect of in-school saccadic training on reading performance. In this cross-over design, study participants (n=327, 165 males; mean age (SD): 7yrs-6mos (1yr-1mo)) were randomized into treatment and control groups then underwent eighteen, 20-minute training sessions over five weeks utilizing King-Devick Reading Acceleration Program Software. Pre- and post-treatment reading assessments included: fluency, comprehension, and rapid number naming performance. The treatment group had significantly greater improvement compared to the control group in fluency (6.2% vs. 3.6%, p=0.0277) and comprehension (7.5% vs. 1.5%, p=0.0002). The high-needs student group significantly improved in fluency (p<0.001) and comprehension (p<0.001). We hypothesize these improvements to be attributed to the repetitive practice of reading-related eye movements, shifting visuospatial attention, and visual processing. Consideration should be given to teaching the physical act of reading within the early education curriculum.

Summary Points:

- ✓ Students in 1st and 2nd grade were enrolled in 6 weeks of King-Devick Reading Acceleration training.
- ✓ The treatment group scored significantly higher in reading fluency and comprehension compared with the control group.
- ✓ A subgroup analysis was performed on high needs students, who were students with an active IEP or in reading recovery programs. Overall, high needs students went from 26th to 40th national percentile rank in reading fluency and from 40th to 56th in comprehension after RAP.
- ✓ The King-Devick Test, an eye movement test used for reading screening, may be used to predict below-average reading performance.



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The Effect of Saccadic Training on Early Reading Fluency

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Background: Eye movements are necessary for the physical act of reading and have been shown to relate to underlying cognitive and visuoattentional processes during reading. The purpose of this study was to determine the effect of saccadic training using the King-Devick remediation software on reading fluency.

Methods: In this prospective, single-blinded, randomized, crossover trial, a cohort of elementary students

received standardized reading fluency testing pre- and posttreatment. Treatment consisted of in-school training 20 minutes per day, 3 days per week for 6 weeks. **Results:** The treatment group had significantly higher reading fluency scores after treatment ($P < .001$), and posttreatment scores were significantly higher than the control group ($P < .005$). **Conclusions:** Saccadic training can significantly improve reading fluency. We hypothesize that this improvement in reading fluency is a result of rigorous practice of eye movements and shifting visuospatial attention, which are vital to the act of reading.

Summary Points:

- ✓ Students in grades 1st through 3rd enrolled in a 6-week long Reading Remediation program to train reading-related eye movements.
- ✓ King-Devick Reading Remediation significantly improved reading fluency.
- ✓ At the 1-year follow-up reading fluency scores remained significantly higher than before K-D Remediation.
- ✓ K-D Remediation shows promising results in improving early reading fluency.



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Oculomotor Training using King-Devick Remediation Elementary School Reading Fluency Outcomes

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Oculomotor training has been associated with improvements in reading fluency, but the physical act of reading is not typically taught in schools. The purpose of this retrospective study was to examine reading fluency outcomes in elementary students following oculomotor training. Methods: Pre- and post-training Scholastic Reading fluency benchmarks were reviewed for nine students (Grade1 through 4) who had undergone 6-week in-school training using King-Devick (K-D) Remediation software. Results: All students demonstrated improvement in reading fluency scores following training and this was statistically significant ($p=0.008$, Wilcoxon signed-rank). Conclusion: Findings support prior research that oculomotor training results in improved reading fluency.

Summary Points:

- ✓ Students, grade 1st through 4th participated in 6 weeks of King-Devick Reading Remediation, and underwent pre- and post- standardized reading fluency testing in this pilot study.
- ✓ All students significantly improved in reading fluency following K-D Remediation.
- ✓ The improvement in reading fluency may be attributed to the rigorous practice of eye movements (saccades) and shifts in visuospatial attention, which are necessary for proficient reading.



Presentation at College of Optometrists in Vision Development 2014 Annual Meeting

Oculomotor Training using KD Remediation Improves Reading Fluency

Benjamin Winters; *Washington Vision Therapy Center*

The purpose of this study was to determine if adding oculomotor training, using King-Devick (K-D) Remediation software, to an existing high school reading program would improve reading fluency outcomes. In this prospective, single-blinded, cross-over trial, of high school students ($n=53$) in grades 9 and 10 enrolled in the school's 12-week supplemental reading course, all students received reading

intervention using Scholastic's Reading 180 system (New York, NY). Students were randomized by classroom into 3 groups based on their initial training condition (+K-D Remediation, +Placebo & Scholastic Only) and pre- and post-remediation measures were performed using the K-D Test and Reading Curriculum-Based Measurement (RCBM) reading fluency test. There was a significantly greater percentage improvement in reading fluency scores (WCPM) with combined +K-D Remediation compared to reading intervention with Scholastic Only (7.54% vs. 3.59%, $p = 0.03$). Over the entire training period there was an average increase of 9.88 WCPM during sessions with +K-D Remediation, 4.7 WCPM with Scholastic Only and 2.78 WCPM during +Placebo. Expected improvement of a successful reading program is an increase of 5 WCPM. In this study, reading intervention coupled with oculomotor training using K-D Remediation, resulted in nearly double the expected reading fluency improvement.

Summary Points:

- ✓ This investigation examined the effect of adding K-D Remediation to the Scholastic Reading 180 reading course for students (Grade 9 and 10) receiving supplemental reading instruction.
- ✓ Significant improvements in reading occurred with the addition of K-D Remediation to students' existing reading intervention.
- ✓ The greatest improvement occurred in the placebo to K-D Remediation cross-over group.



Presented at the American Optometric Association's 2012 Annual Meeting in Chicago, IL

The King-Devick Test as a Reading Fluency Training Program For Students in Elementary Schools

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The King-Devick Test is an established eye movement test that has been used historically to detect reading disorders related to poor visual-motor skills. Seventeen students in grades 2-4 from the St. Elizabeth School in Chicago Illinois, a predominantly African American K-8 school, were screened for reading inefficiency using the King-Devick Test (K-D Test) and assessed in reading fluency using the Scholastic Fluency Test pre- and post-treatment. The control group had a mean-word improvement of 13.11 words as compared to a 30.02 mean word improvement in the treatment group ($p = 0.0413$). Sub-group analysis of grades 2 and 3 showed a mean word improvement of 31.94 among the treatment group as compared to 13.11 for the placebo group ($p = 0.0267$). Reading fluency measures significantly improved following eye movement training.

Summary Points:

- ✓ Reading fluency significantly improved following 6 weeks of Rapid Number Naming training in 2nd and 3rd grade students.
- ✓ 4th grade student's reading performance improved slightly, but not as much as 2nd and 3rd grade indicating there is likely an optimal time to implement eye movement training.
- ✓ Eye movement training programs should be considered as a part of the reading curriculum in schools.