King-Devick Test for Concussion


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 neuropsychological sequelae. This review will focus on the neuropsychological 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 vestibulo-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 managing concussion include eye movement tracking devices, pupillary assessment, computerized testing, imaging modalities, and eletrophysiologic 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.


The Neuro-ophthalmology of Head Trauma
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SUMMARY: 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.

Poster Presentation at American Academy of Neurology Sports Concussion Conference 2014

Vision-Based Performance Testing as a Complement to SCAT3/Child-SCAT3 in Youth and Collegiate Athletes
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OBJECTIVE: We examined the King-Devick (K-D) test of rapid number naming as a complement to the SCAT3/Child-SCAT3 for sideline diagnosis in youth and collegiate athletes.

BACKGROUND: Identification of rapid yet simple diagnostic tests is critical since athletes frequently under-report or do not recognize symptoms of concussion. SCAT3/Child-SCAT3 includes cognition and balance, but does not include a vision-based performance measure. Adding vision increases diagnostic power and performance measures are more practical than neurological exam- or technology-based tests since even parents of youth athletes can perform them.

DESIGN/METHODS: Members of a youth ice hockey and lacrosse league and collegiate athletes from NYU and Long Island University (LIU) participated in a prospective study to examine K-D, SAC (cognition) and timed tandem-gait (balance). K-D is a timed test for which athletes read numbers aloud from three test cards.
**RESULTS:** Youth (n=242, mean age 11.0±2.8 years, range 5-17) and collegiate athletes (n=89, age 19.8±1.4 years, range 18-23) underwent baseline testing. Youth athletes completed K-D in 60.6±22.3 seconds, timed tandem-gait in 15.5±5.2 seconds; median SAC scores were 26 points (range 10-30). Baseline KD scores improved with increasing age in the youth cohort (p<0.001, linear regression). Among the 12 athletes with concussion during their season, K-D worsened from baseline by an average of 5.2 seconds; improvement by 6.4 seconds was noted for non-concussed controls (n=14). K-D showed the greatest capacity to distinguish concussed vs. control groups based on changes from baseline (ROC curve areas from logistic regression models, accounting for age= 0.92 for K-D, 0.87 for tandem, 0.68 for SAC, p=0.0004 for comparison of areas).

**CONCLUSIONS:** Rapid number naming is a useful visual performance tool to diagnose concussed athletes at youth and collegiate levels. Adding a rapid and simple vision-based test to the cognitive and balance performance measures of SCAT3/Child-SCAT3 enhances detection capabilities of current sideline testing.

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**Neurology Clin Pract. 2014**

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


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We examined the King-Devick (K-D) test, a vision-based test of rapid number naming, as a complement to components of the Sport Concussion Assessment Tool, 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.

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

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OBJECTIVE: 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 sideline 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 sideline 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, pb0.01, R2=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, R2=0.25, linear regression). In two players tested sideline 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. CONCLUSION: 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.

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. METHOD: A prospective cohort study was conducted on two teams participating in an amateur rugby league. All players were tested for signs of concussion utilising 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.”
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.

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 (KD) 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 KD 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 KD (37 per 1000 match hours). Witnessed concussions recorded, on average, a longer KD on the day of injury (5.5±2.4 s) than unrecognised concussions (4.4±0.9 s) when compared with their baseline KD. DISCUSSION: The KD 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 KD 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.
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.

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

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The King-Devick (KD) 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 KD as a concussion diagnostic tool is not validated.

PURPOSE: To examine the diagnostic value of KD, by comparing KD with post-concussion symptom scale (PCSS) and ImPACT® composite scores. We hypothesized that KD 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 KD and PCSS across recovery.

METHODS: Thirty-five concussed individuals (12-19 y; 18 female, 17 male) were evaluated with PCSS, ImPACT® composite and KD scores over four clinical visits (V). RESULTS: KD times improved with each visit (ΔV1-V2: 7.86±11.82; ΔV2-V3: 9.17±11.07; ΔV3-V4: 5.30±7.87 sec) and paralleled improvements in PCSS (ΔV1-V2: 8.97±20.27; ΔV2-V3: 8.69±14.70; ΔV3-V4: 6.31±7.71), RT (ΔV1-V2: 0.05±0.21; ΔV2-V3: 0.09±0.19; ΔV3-V4 0.03±0.07) and VMS (ΔV1-V2: -5.27±6.98; ΔV2-V3: -2.61±6.48; ΔV3-V4: -2.35±5.22). Longer KD 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 KD has utility in concussion evaluation. Validation would further establish KD as an effective ancillary tool in longitudinal concussion management and research.

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.

**Journal of Child Neurology**

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

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**Abstract:** 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.

**Annals of Internal Medicine**

Established in 1927 by the American College of Physicians

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.”

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

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

“Such tools as well as balance tests may be used either by trained responders as part of an acute sideline or in-field assessment or by health care providers during subsequent clinical evaluation”
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 (KD) visual screening test to obtain baseline readings prior to any match participation. Over the course of the season, all players were to complete a KD 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 KD test. Additionally, in order to address the concern of fatigue as a contributing factor to the decline of a KD score, players were administered the KD test two minutes after a modified repeat high intensity endurance test (RHIET), which included a series of intensive sprints.

| Table 1: Age, Reported Concussion History, King-Devick Scones and Post-Concussion Symptom Scares With Percentages, Median Scores and Ranges For Amateur Rugby Union Players Competing In a Domestic Competition In New Zealand |
|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Age at baseline ± SD, yrs | No previous concussion (n = 7) | Previous concussion (n = 30) | All players (n = 37) |
|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Number of concussions, mean (range) | 23.0 ± 57 | 21.0 ± 14 | 22.0 ± 4.0 |
| Stand down period completed (%) | 0 | 4.0 (1-11) | 40 (1-11) |
| Medical clearances to KDP (%) | 12 (32.4) | 12 (32.4) | 12 (32.4) |
| King-Devick baseline test | 14 (2-21) | 14 (2-21) | 14 (2-21) |
| Pre-completion test 1, s, median (range) | 50.0 (29.0-83.0) | 50.4 (39.8-86.7) | 50.0 (29.0-86.7) |
| Pre-completion test 2, s, median (range) | 47.3* (28.0-80.3) | 48.9* (39.2-73.0) | 47.3* (28.0-80.3) |
| Difference, s, median (range) | -26 (~15.7-0.0) | -28 (~13.7 to -0.6) | -26 (~15.7-0.0) |
| Baseline post-concussion symptom scale | 0 (0-6) | 0 (0-6) | 0 (0-6) |
| Physical, median (range) | 0 (0-3) | 0 (0-6) | 0 (0-6) |
| Cognitive, median (range) | 0 (0-2) | 0 (0-2) | 0 (0-2) |
| Sleep, median, (range) | 0 (0-2) | 0 (0-2) | 0 (0-2) |
| Emotional, median (range) | 0 (0-2) | 0 (0-2) | 0 (0-2) |

RIP return to play; s, seconds; Significant difference (P < .05) than “Pre-completion tests.
Reprinted from Journal of the Neurological Sciences, Vol 326/1-2, King D, Brughelli M, Hume P, Gissane C, Concussions in amateur rugby union identified with the use of a rapid visual screening tool, Pages No. 59-63, 2013, with permission from Elsevier.

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 KD test (Table 1 from paper). A decline in KD 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 KD 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 KD test time and actually improved KD 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.

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


**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 SCAT2 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.

**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. Sports 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.
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."

**Sports-Related Concussion Testing**

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**Vision-Based Performance Testing as a Complement to SCAT3/Child-SCAT3 in Youth and Collegiate Athletes**

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**OBJECTIVE:** We examined the King–Devick (K–D) test of rapid number naming as a complement to the SCAT3/Child-SCAT3 for sideline diagnosis in youth and collegiate athletes.
BACKGROUND: Identification of rapid yet simple diagnostic tests is critical since athletes frequently under-report or do not recognize symptoms of concussion. SCAT3/Child-SCAT3 includes cognition and balance, but does not include a vision-based performance measure. Adding vision increases diagnostic power and performance measures are more practical than neurological exam- or technology-based tests since even parents of youth athletes can perform them.

DESIGN/METHODS: Members of a youth ice hockey and lacrosse league and collegiate athletes from NYU and Long Island University (LIU) participated in a prospective study to examine K-D, SAC (cognition) and timed tandem-gait (balance). K-D is a timed test for which athletes read numbers aloud from three test cards.

RESULTS: Youth (n=242, mean age 11.0±2.8 years, range 5-17) and collegiate athletes (n=89, age 19.8±1.4 years, range 18-23) underwent baseline testing. Youth athletes completed K-D in 60.6±22.3 seconds, timed tandem-gait in 15.5±5.2 seconds; median SAC scores were 26 points (range 10-30). Baseline KD scores improved with increasing age in the youth cohort (p<0.001, linear regression). Among the 12 athletes with concussion during their season, K-D worsened from baseline by an average of 5.2 seconds; improvement by 6.4 seconds was noted for non-concussed controls (n=14). K-D showed the greatest capacity to distinguish concussed vs. control groups based on changes from baseline (ROC curve areas from logistic regression models, accounting for age= 0.92 for K-D, 0.87 for tandem, 0.68 for SAC, p=0.0004 for comparison of areas).

CONCLUSIONS: Rapid number naming is a useful visual performance tool to diagnose concussed athletes at youth and collegiate levels. Adding a rapid and simple vision-based test to the cognitive and balance performance measures of SCAT3/Child-SCAT3 enhances detection capabilities of current sideline testing.

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.

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. 

DESIGN/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.
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 injury 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.

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 (intra-class 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.

Baseline Concussion Testing in Different Environments: A Pilot Study
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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.

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."

**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, athletes, and coaches; 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 and training 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."

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

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**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. **Method:** 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, R² = 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.

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

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**PURPOSE**: To evaluate the effectiveness of the King-Devick (KD) 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 KD 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 KD 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 KD 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 KD 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 KD 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.