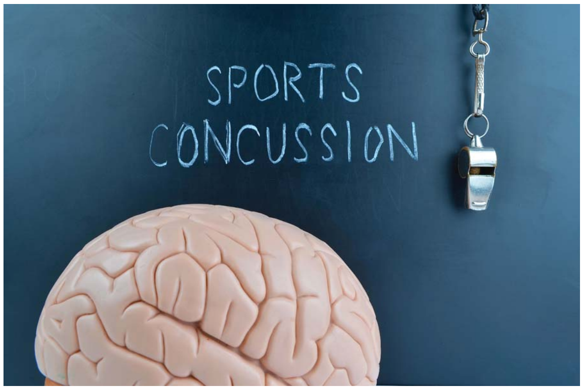
King-Devick Test identifies real-time concussion and asymptomatic concussion in youth athletes

Priya S. Dhawan, MD; Danielle Leong, OD, PhD; Lisa Tapsell, REEGT; Amaal J. Starling, MD; Steven L. Galetta, MD; Laura J. Balcer, MD, MSCE; Trenton L. Overall, DO; Jennifer S. Adler; Rashmi B. Halker-Singh, MD; Bert B. Vargas, MD; David Dodick, MD

Abstract

Background: Sports concussion has an annual incidence of approximately 3.8 million. Over half go unreported and a substantial number may be asymptomatic. A rapid, cost-effective, and reliable tool that facilitates diagnosis of concussion is needed. The King-Devick (K-D) test is a vision-based tool of rapid number naming for assessment of concussion. In this study, we evaluated the utility of the K-D test in real time for identification of symptomatic concussion in youth athletes and to determine if similar impairment (subclinical concussion) exists in youth athletes without an obvious head injury or symptoms. **Methods:** Youth hockey players underwent K-D testing preseason, postseason, and immediately after suspected concussion. Additional testing was performed in a subgroup of nonconcussed athletes immediately before and after a game to determine effects of fatigue on K-D scores. **Results:** Among 141 players tested, 20 had clinically diagnosed concussion. All 20 had immediate postconcussion K-D times >5 seconds from baseline (average 7.3 seconds) and all but 2 had worse postseason scores (46.4 seconds vs 52.4 seconds, $p < 0.05$, Wilcoxon signed rank test). Nonconcussed athletes saw minimal improvement postseason (43.9 seconds vs 42.1 seconds, $p < 0.05$) and 51 nonconcussed players assessed before and after a game revealed no significant time change as a result of fatigue. **Conclusions:** Rapid number naming using the K-D test accurately identifies real-time, symptomatic concussion in youth athletes. Scores in concussed players may remain abnormal over time. Athletes should undergo preseason and postseason K-D testing, with additional evaluation real time to inform the assessment of suspected concussion. **Classification of Evidence:** This study provides Class III evidence that the K-D test accurately identifies real-time concussions in youth athletes. *Neurol Clin Pract* **2017;7:464–473**



Department of Neurology (PSD, LT, AJS, TLO, RBH-S, BBV, DD), Mayo Clinic Arizona, Phoenix; King-Devick Test, Inc. (DL), Oakbrook Terrace, IL; Departments of Neurology (SLG, LJB), Ophthalmology (SLG, LJB), and Population Health (LJB), New York University Langone Medical Center, New York; Departments of Neurology (SLG, LJB) and Biostatistics and Epidemiology (LJB), University of Pennsylvania School of Medicine, Philadelphia; and University of Arizona (JSA), Scottsdale.

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Correspondence to: Dodick.david@mayo.edu

Increasing public awareness of concussion and possible long-term consequences on brain function[1] are becoming a growing concern. However, recent data reveal that athletes often underreport concussion symptoms.[2,3] This underscores the need for quick, objective tools on the sidelines to identify when a meaningful head injury has occurred and aid in timely removal from play.

As vision accounts for more than half of the brain's pathways, vision-based testing is well-suited to detect neurologic impairment resulting from concussion. The King-Devick (K-D) test is a timed performance measure of rapid number naming that requires intact vision and eye as well as other functions such as attention, concentration, and language.[4] Individual performance is compared to an established individual preseason baseline.[4] Literature has indicated that diffuse brain injury and suboptimal brain function as a result of concussion correlates with worsening of K-D performance[4–16] as well as greater identification of concussed athletes at the time of suspected injury when the K-D test was added to other commonly used sideline concussion assessment tools.[6,12]

The K-D test has high sensitivity, specificity, and test–retest reliability,[4,10,11,16] can be completed in under 2 minutes, and can be administered by non–medically trained personnel. These features afford this test great practical utility in youth and high school athletes, many of whom do not have the same access to medical personnel during competition as do collegiate and professional athletes. The purpose of this investigation was to examine the utility of the K-D test for real-time identification of concussion in youth hockey players.

METHODS

Primary research question

Does the K-D test accurately identify real-time concussions in youth athletes?

Classification of evidence

Class III evidence.

Standard protocol approvals, registrations, and patient consents

The Mayo Clinic institutional review board approved all study protocols. Child assent and parent or guardian informed consent were obtained from all participants.

Study participants

This study enrolled high school level hockey players (n = 141) from the Arizona High School Hockey Association during a 20-week season. All participants underwent K-D test preseason baseline testing. During the season, participants who sustained head injury or were suspected of concussion were tested rinkside. Concussion was defined as a blow to the head or body resulting in temporary or prolonged alteration in cognition, with or without loss of consciousness. Additional testing was performed in a nonconcussed athlete subgroup immediately before and after a game to examine the effects of sport-related fatigue on K-D performance. Postseason testing was also completed to determine the effects of a playing a full season on K-D scores and to examine the postseason differences between concussed and nonconcussed athletes.

The K-D test

The K-D test is a 2-minute vision-based test of rapid number naming that requires functioning vision, eye movements, attention, language, and concentration pathways to complete successfully. Participants are asked to quickly and accurately read aloud a series of numbers on test cards (figure 1). The test cards 1 through 3 become progressively more challenging as number targets on card 1 are separated with guide lines. On card 2, these guide lines are removed and the numbers are spread out, and on card 3, the vertical crowding of number targets occurs. The time to complete the test comprises the K-D score. Previous studies have demonstrated that a worsening of the K-D test summary score (increase in time to perform) after head

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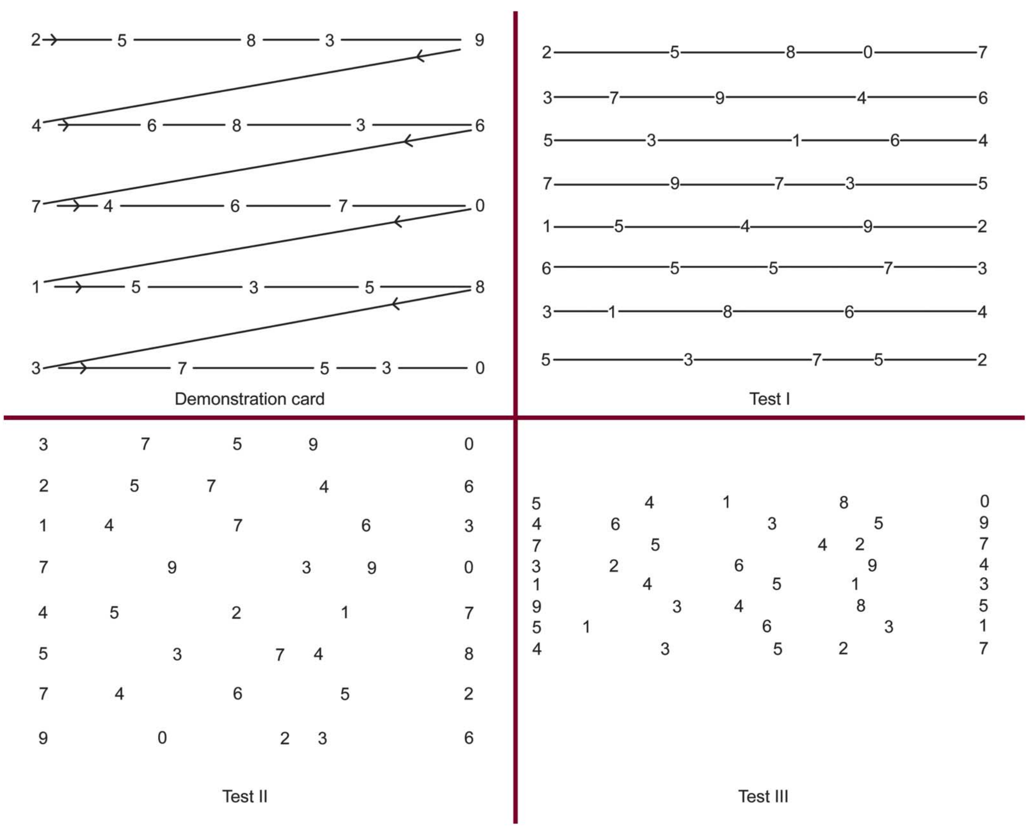
injury is highly suggestive of concussion.[4–6,8,11,16,17] K-D test performance has been shown to be robust to various testing environments and noise levels[5,18] and high test–retest reliability (intraclass correlation coefficient 0.90–0.97) has been demonstrated.[4,10,11] Examinations of physical fatigue have demonstrated that in the absence of concussion, physical exercise is associated with modest improvement in K-D test time,[5,6,8,10,11] reflecting learning effects commonly seen in performance measures.[19] The K-D test is available as a computer- or tablet-based application with standardized testing instructions. The K-D test v1.1.0 was utilized in this study.

Testing procedures

In this study, a preseason concussion history was recorded for all athletes. A concussion history was defined as either a previous clinical diagnosis or history of symptoms consistent with

Figure 1 Demonstration and test cards for the King-Devick (K-D) Test



To perform the K-D test, participants are asked to read the numbers on each card from left to right as quickly as possible but without making any errors. Following completion of the demonstration card (upper left), participants are then asked to read each of the 3 test cards in the same manner. The times required to complete each card are recorded in seconds using a stopwatch. The sum of the 3 test card time scores constitutes the summary score for the entire test, the K-D time score.

Table Concussion history, changes in King-Devick (K-D) score, and postseason K-D score

	Concussed (n = 20)	Non-concussed (n = 121)
Positive history of concussion, n (%)	7 (35); $p = 0.0034$[a]	12 (10)
Change in K-D baseline vs rinkside, s, mean ± SD (range)[b]	7.3 ± 2.5 (5.0–16.0)	
Change in K-D pregame vs postgame (n = 51), s, mean ± SD (range)[b]		−0.6 ± 0.6 (−2.0 to 0.0)

[a] *p* Value from signed-rank test comparing concussed vs nonconcussed athletes with history of concussion.

[b] Positive numbers for change in K-D indicate worsening in score. Negative number for change in K-D indicates improvement in score.

a concussion in the setting of an impact to the head or body. K-D baseline and postseason testing was performed rinkside. K-D baseline testing was performed before contact and collision play with multiple individuals being tested simultaneously by study personnel. Athletes were given standardized instructions for the K-D test. Coaches were instructed by our study team in detection of concussion, as they made the initial screening and immediate decision to remove a player from play. When concussion was suspected, the K-D test was administered rinkside by trained volunteers (coaches and parents) using standardized instructions. Trained volunteers were used because of their consistent presence, their ready access to the athletes, and to ensure that athletes were evaluated as soon as possible after a suspected concussion. Times and errors were compared to the athlete's baseline. In addition, a subgroup of nonconcussed athletes was tested immediately before and after a game to evaluate effects of physical exercise and fatigue on K-D performance, independent of concussion. The diagnosis of concussion was confirmed by clinical evaluation with the player's primary or (if needed) an emergency room physician, which was recommended to occur within 24 hours of concussion. These physicians were neither aware of the K-D test scores nor of its administration. K-D scores in no way influenced the evaluation or management of players.

Data analysis

Data were analyzed using SAS (SAS Institute, Cary, NC) JMP. Descriptive statistics were used to summarize the continuous measures. Change in baseline and postseason K-D time scores were compared and similarly differences in baseline and rinkside for concussed athletes were compared using 2-sided *t* test. Two-sided *t* test was used to compare K-D time scores pregame and postgame for the subgroup of nonconcussed athletes. History of concussion was compared between concussed vs nonconcussed athletes using 2-sided *t* test. Statistical significance was set at $p < 0.05$. The ability for K-D test to predict concussion diagnosis was determined by logistic regression and determination of areas under the receiver operating characteristic (ROC) curves.

RESULTS

There were a total of 141 participants, aged 15.5 ± 1.1 years (range 13–18 years, 100% male). Twenty athletes sustained concussion during the playing season. No players initially suspected of having concussion were later determined not to have sustained one. All 20 concussed athletes demonstrated >5 seconds worsening on rinkside K-D testing compared to baseline. Concussed athletes demonstrated a 7.4-seconds average worsening from baseline ($p < 0.0001$; table). Conversely, 51 nonconcussed athletes tested before and after competition to examine effects of fatigue displayed mild improvement in K-D test scores (table). Although postseason testing of nonconcussed athletes demonstrated mild improvement of

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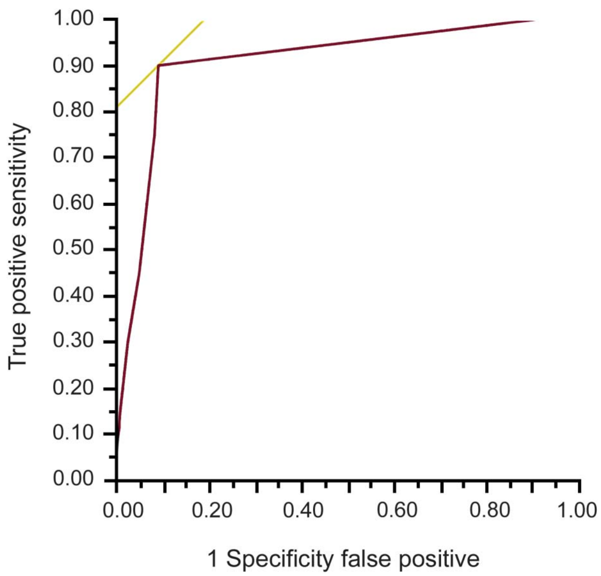
K-D summary scores (43.9 vs 42.1 seconds, $p < 0.05$, Wilcoxon signed rank test) consistent with known learning effects in the absence of concussion, concussed players had worsening from preseason to postseason (mean + 3.5 seconds, 2-sided p value < 0.0001), and all but 2 concussed athletes demonstrating worse postseason scores (46.4 vs 52.4 seconds, $p < 0.05$, Wilcoxon signed rank test). Thirteen percent of all participants reported a positive history of concussion. Eleven athletes who were not identified as concussed and did not report symptoms consistent with a concussion during the season had worse postseason times from baseline (48.8 vs 45.0 seconds). Concussed participants were more likely to have had a prior concussion than the nonconcussed participants (35% vs 10%, $p = 0.0034$, table). In a patient clinically suspected of having a concussion, ROC analysis to predict a diagnosis of concussion showed that the optimal cutoff point in this cohort was 2 seconds, indicating that a worsening of 2 seconds or greater was predictive for concussion (sensitivity 90%, specificity 91%, area under the curve 0.91) (figure 2).

DISCUSSION

In this study of youth ice hockey players, concussed athletes had worsening of K-D time scores compared to nonconcussed athletes when compared to their preseason baseline. This finding was similar to previous studies and demonstrated an average worsening of score from baseline

Figure 2 **Receiver operating characteristic (ROC) curve of King-Devick (K-D) test for distinguishing concussed from nonconcussed athletes**



ROC curve areas represent the probability that a test can distinguish concussed from nonconcussed athletes, and range from 0.5 (probability no better than chance) to 1.0 (perfect ability to distinguish). Area under the curve = 0.91. The optimal cutoff point of 2 seconds worsening predicts concussion (sensitivity 90%, specificity 91%).

ranging from 5 to 7 seconds after concussion. ROC curves of data from this study suggest that a K-D worsening of 2 seconds or more is highly predictive for a clinical diagnosis of concussion with both high sensitivity and high specificity. These results further support the K-D test, a vision-based test of rapid number naming, as a useful sideline tool to aid in the real-time detection of concussion.

Prior concussion has been recognized as a risk factor for subsequent concussion. A study of collegiate football athletes[20] found that a history of 3 or more previous concussions increased the risk of subsequent concussion by 3 times as compared to those with no concussion history. Similarly, those with any history of concussion showed elevated risk of subsequent concussion. This was evident in the present study, in which concussed athletes were more likely to have a positive concussion history compared to nonconcussed athletes. Interestingly, this study also showed that K-D scores remained abnormal over time in a majority of concussed youth athletes, suggesting that K-D may also assist in identification of symptomatic concussion over time in youth high school athletes. These findings are similar to recent data[17] illustrating that the K-D test may be effective in objectively monitoring long-term recovery and symptom resolution in concussed adolescents.

In a study of elite-level ice hockey players,[9] worsened K-D times were associated with worse Standardized Assessment of Concussion Immediate Memory scores ($R^2 = 0.62$, $p < 0.0001$). Similarly, studies of concussed boxers and mixed martial arts fighters[4] showed correlation between worse K-D scores and poor performance on the Military Acute Concussion Evaluation cognitive test ($r_s = -0.79$, $p = 0.0001$). Collectively, these associations are likely reflective of the abnormalities in neurophysiologic pathways these tests evaluate.

Tasks involved in the K-D test require the functional integration of the brainstem, cerebellum, and cerebral cortex, making the test particularly valuable in the setting of concussion. Vision alone engages more than half of the brain's circuits.[21] Eye movement (accommodative, vergence, and saccadic) pathways are complex, involving precise coordination of ocular muscles with integration of cortical and subcortical eye movement regions. Cortical areas involved in eye movement, planning, initiation, and execution include the frontal eye fields, the dorsolateral prefrontal cortex, the supplementary motor area, the posterior parietal cortex, the middle temporal area, and the occipital lobe with the striate cortex.[22–26] Other subcortical structures involved include the thalamus, superior colliculus, and other structures within the brainstem.[23] This widely distributed network of pathways makes vision testing effective in detecting sports-related head trauma. As such, vision-based testing has been shown to become impaired following even mild traumatic brain injury.[27–31]

Correlations have been shown between K-D scores and Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) visual motor scores at baseline,[18] indicating that the K-D test appears sensitive to visual performance-related effects of concussion. Given that concussed athletes in this study similarly showed persistent K-D deficits postseason, and results of a previous study examining the effects of a high school football season on K-D performance[19] that revealed improvement in K-D test scores in the absence of concussion, we propose that athletes not initially identified as having concussion who later displayed K-D deficits on postseason follow-up may have sustained unidentified or unreported concussion during the season; however, since clinical details were not obtained in this study, other factors that may have contributed to worsening performance cannot be ruled out. Prior studies on rugby players[7,8,32] have reached similar conclusions and further study is necessary to better understand the importance of these observations. In a recent investigation, sideline medical personnel screened nearly all rugby players with K-D testing postmatch. Though only 8 concussive events were clinically recognized, K-D test results identified 44 additional athletes in whom no head injury was witnessed nor were there any symptoms reported. The large disparity with 6 times more unwitnessed than witnessed concussive incidents supports recent work suggesting that numerous concussions go undetected and undiagnosed.[33,34] Furthermore, combining witnessed and unwitnessed concussive incidents results in a 10 times higher concussion rate than what had been previously reported and supports literature that currently reported rates are likely underestimated.[33]

In the absence of concussion, results of this study demonstrated learning effects on K-D test performance, similar to previous studies.[4–13,32] This is commonly associated with performance measures of timed testing in which there is improvement in completion time between test administrations. In the present study, results of nonconcussed players examined immediately before and after a game displayed improvement in K-D scores, confirming previous work that K-D test performance does not seem to worsen in the setting of fatigue.[5,8,10,11] This learning effect is observed after sport-related physical fatigue, as experienced by athletes in practice or game situations.

The results of this study should be interpreted in the context of the study's limitations. Correction for multiple comparisons, such as a Bonferroni correction, was not used in the analysis. While reasonable, the sample size was modest and restricted to male ice hockey players. These results therefore require confirmation in a similar-sized or larger sample and in a more diverse population that includes female athletes and other sports. However, similar results regarding the sensitivity of the K-D test in youth concussion was recently demonstrated in junior rugby athletes in a sample that included female athletes and in another youth cohort.[6,32] That K-D test administered rinkside during a suspected concussion was performed by trained volunteers and not study personnel may have introduced variability in the approach to administering the K-D test and therefore in internal consistency and reliability of the results.

Future studies examining the utility of the K-D test in following long-term cognitive function as compared to baseline scores are indicated. The 11 clinically nonconcussed players in our study who exhibited prolonged postseason K-D times suggests that perhaps this test is useful not only as a sideline assessment of concussion but as a longitudinal screening tool, abnormalities in which would prompt more detailed concussion testing. Our study was not designed to prospectively follow players after one season, and thus we can only hypothesize as to the importance of the findings in these 11 players. Postseason worsening in test performance is an area for further investigation.

Detecting concussion on the sidelines, and timely removal of athlete from play, can minimize the deleterious outcomes of concussion, repeat injury, and the cumulative effects of repetitive head trauma. Rapid screening tools that are practical for the sideline evaluation of athletes are important for implementation. These tools can help provide a protocol and a consistent structure to the evaluation of athletes with suspected concussion. The literature has shown that K-D times decrease (improve) with increasing age of youth athletes[6] and that normative values are not effective in the acute assessment of injury.[35] This highlights the importance of determining a new baseline score at least annually. Due to the simplicity of measuring the time to complete and comparing to baseline scores, the K-D test can be accurately and easily administered by non–medically trained observers such as parents on the sidelines.[10] This makes it a realistic tool for youth sports, which often lacks access to medical personnel. As the K-D test has been shown to complement the sideline evaluation,[6,12] it should supplement and not substitute clinical or parental judgment.

The results of this study further support the K-D test as accurate for the identification of symptomatic concussion in youth athletes at the time of suspected concussion. Athletes should undergo preseason baseline K-D testing and additional evaluation at the time of suspected concussion to assist in the diagnosis of concussion. The inclusion of this practical and easy to administer vision-based tool may assist in improving concussion detection and minimize the potential for subsequent injury. K-D scores of concussed athletes may become abnormal over time, indicating that the K-D test may be helpful in the monitoring of players for concussion. Future studies will further examine the utility of the K-D test in monitoring recovery.

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AUTHOR CONTRIBUTIONS

P.S. Dhawan: conception and design, analysis and interpretation of data, drafting and revising article. D. Leong: analysis and interpretation of data, drafting and revising article. L. Tapsell: conception and design, analysis and interpretation of data, drafting and revising article. A.J. Starling: conception and design, analysis and interpretation of data, drafting and revising article. S.L. Galetta: conception and design, analysis and interpretation of data, drafting and revising article. L.J. Balcer: conception and design, analysis and interpretation of data, drafting and revising article. T.L. Overall: conception and design, analysis and interpretation of data, drafting and revising article. J.S. Adler: conception and design, analysis and interpretation of data, drafting and revising article. R.B. Halker-Singh: conception and design, analysis and interpretation of data, drafting and revising article. B.B. Vargas: conception and design, analysis and interpretation of data, drafting and revising article. D. Dodick: conception and design, analysis and interpretation of data, drafting and revising article.

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Continued Healthcare Learning, Meeting LogiX, Health LogiX, and Wiley Blackwell; holds stock options in GBS/Nocira, Epien, and Mobile Health; serves on the board of King-Devick Inc.; has a consulting use agreement with the National Academies of Sciences, Engineering, and Medicine; has received funding for travel from Allergan, Amgen, Alder, Dr Reddy's, Merck, Promius, eNeura, Eli Lilly & Company, Autonomic Technologies, Teva, Trigemina, GBS, Colucid, Zosano, Laydenburg Thalmann, Biocentric, Biohaven, Magellan, and Pfizer (Japan); serves on the Editorial Boards of *Headache*, *Cephalalgia*, *Lancet Neurology*, and *Postgraduate Medicine*; is author on a patent re: Injection paradigm for administration of botulinum toxins; and performs the King-Devick test as part of routine clinical assessments in concussion program at Mayo Clinic Arizona. Full disclosure form information provided by the authors is available with the **full text of this article at Neurology.org/cp**.

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