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The King–Devick test and sports-related concussion: Study of a rapid visual screening tool in a collegiate cohort☆,☆☆

Kristin M. Galetta [a], Lauren E. Brandes [a], Karl Maki [a], Mark S. Dziemianowicz [a], Eric Laudano [b], Megan Allen [c], Kathy Lawler [a], Brian Sennett [d], Douglas Wiebe [e], Steve Devick [f], Leonard V. Messner [c], Steven L. Galetta [a,g], Laura J. Balcer [a,e,g,*]

[a] Department of Neurology, University of Pennsylvania School of Medicine, Philadelphia, PA, USA
[b] Department of Recreation and Intercollegiate Athletics, Athletic Training, University of Pennsylvania, Philadelphia, PA, USA
[c] Illinois College of Optometry, Chicago, IL, USA
[d] Department of Orthopedics, University of Pennsylvania School of Medicine, Philadelphia, PA, USA
[e] Department of Epidemiology, University of Pennsylvania School of Medicine, Philadelphia, PA, USA
[f] King–Devick Test, LLC, Downers Grove, IL, USA
[g] Department of Ophthalmology, University of Pennsylvania School of Medicine, Philadelphia, PA, USA

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ABSTRACT

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. 37.9 s, $P = 0.03$, 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. 37.0 s, $P = 0.009$), with all except one athlete demonstrating worsening from baseline (median 5.9 s).
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.

1. Introduction

With up to 3.8 million Americans sustaining sports-related concussions each year, the importance of accurately diagnosing concussion immediately after injury has become critical [1–9]. Without a clear clinical picture of the evolution of an individual concussive event, medical professionals are left with difficult decisions whether an athlete may return to play. Younger athletes are particularly susceptible to third-party pressures to return to play preemptively, even before assessment [10–14]. Without the data from rapid screening tests to make proper decisions on the side lines, athletes may be at risk for chronic neurological symptoms and pathological changes that have been associated with concussion [15–30].

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* Corresponding author at: Departments of Neurology, Ophthalmology, and Epidemiology, University of Pennsylvania School of Medicine, 3 E. Gates Building, 3400 Spruce Street, Philadelphia, PA 19104, USA. Tel.: +1 215 349 8072; fax: +1 215 662 3362.
E-mail address: lbalcer@mail.med.upenn.edu (L.J. Balcer).

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Concussion, defined by an impulse blow to the head or body that results in transient neurologic signs or symptoms, is largely the result of functional rather than structural injury to the brain [25]. Short-term effects may include second-impact syndrome (a second concussive and potentially catastrophic event before symptoms of the first episode have cleared) [16,17], headache, fatigue, cognitive delay and visual disturbances [20]. Concussion has been associated with chronic effects including depression and altered cognition [18,19] as well as neurodegenerative disorders such as chronic traumatic encephalopathy and Alzheimer's disease [26–30]. These potentially devastating outcomes underlie the need for studies validating sideline tests for diagnosis as well as tools for management of concussion.

While the array of symptoms associated with concussion has evolved immensely in recent years, the tools for objectively measuring and reporting these events remain insufficient. A general consensus among specialists is that there is an unmet need for a test or composite of tests that can quickly and accurately diagnose concussion in sports. Such a test would allow for the proper preventative measures to be taken so that the athlete does not suffer further neurological injury [1,15,31,32]. In a recent study, the King–Devick (K–D) test was shown to have a high degree of test–retest reliability and to be an accurate method for rapidly identifying boxers and mixed martial arts fighters with overt head trauma [33]. The K–D test is based on the detection of impaired eye movements and saccades, a finding that indicates suboptimal brain function [31–35]. In this study of collegiate athletes, we performed initial analyses to investigate the K–D test as a potential acute visual screening test to complement other diagnostic assessments for sports-related concussion. The purpose of this study was to determine the effect of concussion on K–D scores compared to a pre-season baseline. We hypothesized that K–D time scores obtained immediately on the sidelines would be significantly increased (worse) compared to baseline in athletes with concussion.

2. Subjects and methods

2.1. Study participants

For this ongoing longitudinal study, collegiate athletes from the varsity football, sprint football, men's and women's soccer, and men's and women's basketball teams were enrolled during the fall pre-season at the University of Pennsylvania. Written informed consent was obtained from all participants. Study protocols were approved by the University of Pennsylvania Institutional Review Board.

2.2. The King–Devick (K–D) test

The King–Devick (K–D) test is based on the time to perform rapid number naming [33,34]. The test involves reading aloud a series of single digit numbers from left to right on three test cards. Standardized instructions are used; the test requires less than 2 min to administer. The K–D test includes one demonstration card and three test cards (Fig. 1). Participants are asked to read the numbers on each card from left to right as quickly as possible but without making any errors. The sum of the three test card time scores constitutes the summary score for the entire test. Numbers of errors made in reading the test cards are also recorded.

2.3. Military Acute Concussion Evaluation (MACE)

The Military Acute Concussion Evaluation (MACE) was used as a more comprehensive test for concussion that incorporates the Standardized Assessment of Concussion (SAC) [14,36,37]. The MACE is a relatively rapid, stand-alone cognitive test that includes a cognitive history, memory and orientation testing, and a neurological screening [14,36]. Based on the first two components, a total score is given (total possible 30). This test requires approximately 10 min. A total MACE score less than 25 is considered to represent clinically relevant neurocognitive impairment and require further evaluation for brain injury [36].

2.4. Testing procedures

Athletes from all teams were tested during pre-season activities (pre-season baseline). Participants were given standardized instructions for the K–D test. While it was not feasible to perform baseline testing on the sidelines of games during the 2010–11 season, the baseline testing did take place in noisy locker rooms with multiple players being tested simultaneously.

Athletes who sustained concussions in games or practices during the playing season were given the K–D test immediately on the sidelines. Concussion was defined as an impulsive blow to the head or body that resulted in transient neurologic signs or symptoms. Judgments with regard to the occurrence of concussion were made as per standard practice by the athletic trainers on the sidelines. Testing post-trauma was delayed by several days for three (of 13) athletes due to non-head injuries or other issues that precluded sideline testing.

Several pilot sub-group analyses were undertaken in this study, largely dependent upon the availability of the athletes and the willingness of the coach and trainer to have them undergo further testing. 1. Although test–retest and inter-rater reliability for K–D testing have been reported [33], a subgroup of this cohort of collegiate athletes (sprint football team) also had baseline testing performed twice within a 15 minute period during the pre-season by the same examiners. 2. To examine the potential effects of post-game exercise fatigue on K–D scores independent of concussion, players on the men's basketball team were tested immediately following a mid-season scrimmage. 3. Another subgroup of athletes, the women's basketball team, underwent pre-season MACE testing in order to assess correlations between the K–D test and scores for this brief cognitive battery. These subgroup tests could not be performed for all athletes during the 2010–11 season and were added onto the primary protocol to obtain preliminary data for further study.

At the end of the playing season, athletes on all teams were re-tested once using the K–D test, again under conditions of a busy training room or sideline.

2.5. Data analysis

Statistical analyses were performed using Stata 11.0 software. Non-parametric statistical tests were used given the small sample size ($n = 10$) for athletes with concussion and sideline testing. Differences in K–D time scores from pre- to post-season were calculated, and pre- and post-season K–D scores were compared within athletes using the Wilcoxon signed-rank test. For athletes with concussion, sideline K–D scores were compared similarly with pre-season baseline scores, as were scores pre- and post-exercise for the men's basketball team. The relation of pre-season K–D scores to MACE scores was determined using Spearman rank-correlations. Internal consistency reliability for the three test cards vs. total time scores at baseline was measured using Cronbach's alpha. To determine whether K–D scores were similar across the various sports, the Kruskal–Wallis one-way ANOVA by ranks was performed.

3. Results

Characteristics and K–D testing data for the study cohort ($n = 219$) are shown in Table 1. Pre-season K–D scores were similar across sports, with medians ranging from 36.0 to 40.2 s. Lower (better) mean time scores were noted for the second pre-season testing session performed for sprint football players (median 36.1 vs. 40.2 s, $P < 0.0001$, Wilcoxon

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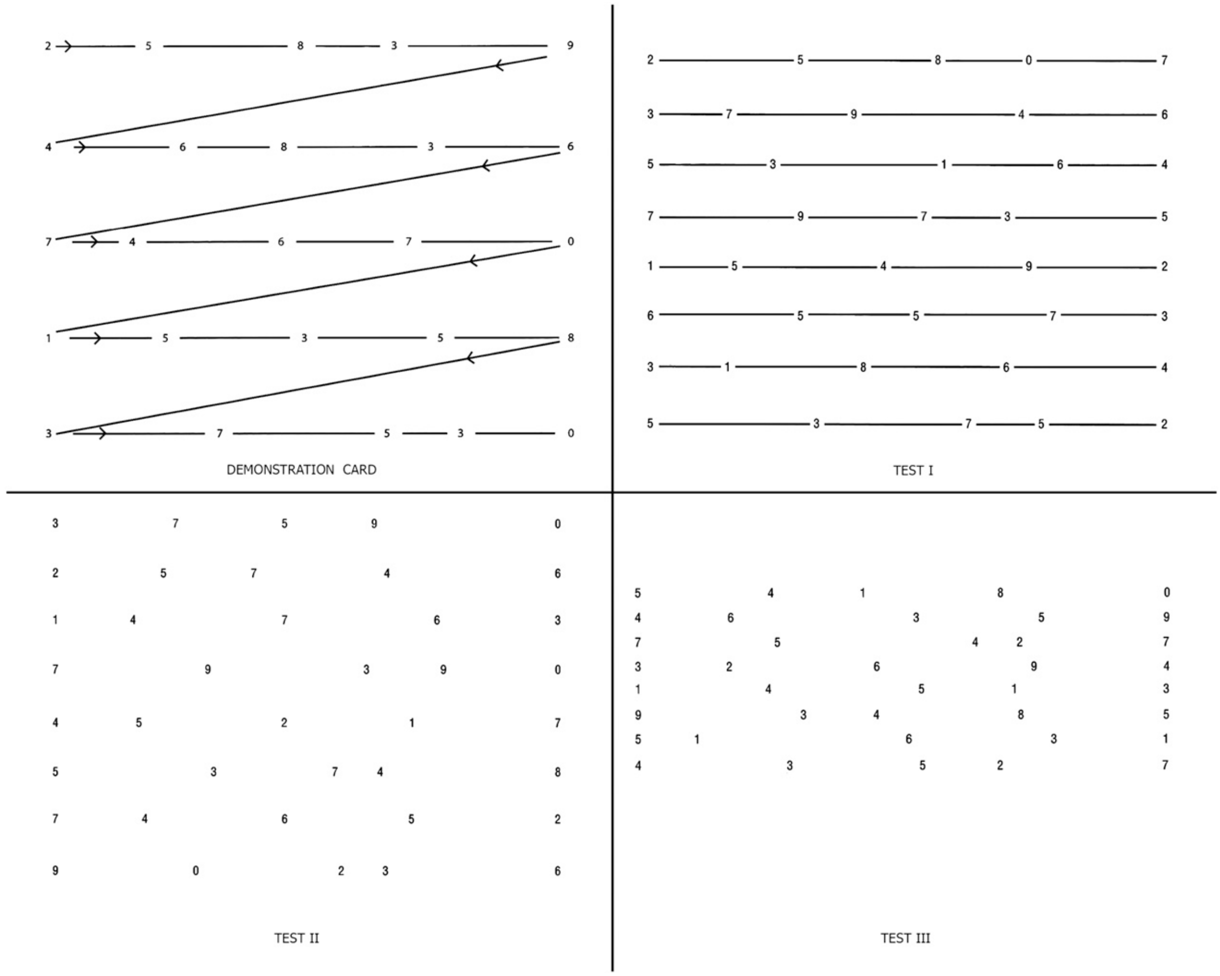

Fig. 1. Demonstration and test cards for the King–Devick (K–D) Test, a candidate rapid sideline screening for sports-related concussion based on the time to perform rapid number naming. To perform the K–D test, participants are asked to read the numbers on each card from left to right as quickly as possible but without making any errors. Following completion of the demonstration card (upper left), subjects are then asked to read each of the three test cards in the same manner. The times required to complete each card are recorded in seconds using a stopwatch. The sum of the three test card time scores constitutes the summary score for the entire test, the K–D time score. Numbers of errors made in reading the test cards are also recorded; mis-speaks on numbers are recorded as errors only if the subject does not immediately correct the mistake before going on to the next number.

signed-rank test). Post-season K–D scores were also minimally lower than the best pre-season scores for the overall cohort (35.1 vs. 37.9 s, $P=0.03$). These observations likely reflect learning effects, a characteristic inherent in many performance measures. Slight learning effects were also noted among the sprint football players ($n=36$) between the two baseline measurements (38.6 vs. 36.1 s, $P<0.0001$, Wilcoxon signed-rank test, Table 1). MACE testing correlated moderately with pre-season K–D scores ($r_s=-0.54$, $P=0.07$). Internal consistency reliability was appropriate, with correlations of 0.70 (test card 1), 0.76 (test card 2) and 0.77 (test card 3) between test card scores and the total time score at baseline (Cronbach's alpha). These correlations are within the desired range for alpha (0.70–0.90) and indicate that each test card contributes information to the overall score yet with minimal redundancy [38]. Significant heterogeneity (overall differences across sports) was noted only for the post-season scores ($P=0.02$), and not for baseline ($P=0.10$) or sideline scores in athletes with concussion ($P=0.29$, Kruskal–Wallis one-way ANOVA by ranks).

Sideline K–D time scores were significantly higher (worse) than the best baseline for athletes who had concussions during games or practices ($n=10$, median 46.9 s post-concussion vs. 37.0 s baseline, $P=0.009$, Wilcoxon signed-rank test, Table 2). The median of the calculated change in scores from pre- to post-season for athletes who did not have concussions was a 0.72 second improvement, while the median change from baseline to sideline testing for those with concussions was a 5.9 second worsening. Among athletes with concussion tested immediately on the sidelines, all except one demonstrated worsening of their K–D score from baseline (range −0.05 to 28.1 s); all were injured during a game. The numbers of errors were few, with one participant making four errors and two others making one error on sideline testing. Interestingly, two of the three athletes with concussion who made errors on sideline testing were those who did not substantially worsen from baseline with respect to their K–D time scores (32.5 s baseline vs. 32.7 s post-concussion for athlete with 4 errors, and 53.4 vs. 55.9 s for another with 1 error).

Importantly, while athletes with concussion showed significant worsening from baseline when tested on the sidelines, those tested immediately following an intense two-hour scrimmage did not demonstrate worsening of their K–D time scores, but instead showed improvement on average from baseline (median 38.6 s baseline vs. 35.0 s post-scrimmage) even in the setting of post-workout fatigue (Fig. 2). Of note, no concussions occurred among the basketball players after the post-scrimmage K–D testing was performed; these post-exercise data was obtained during one of the last practices of the season just before the final season game.

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Table 1
Characteristics of collegiate athlete cohort and K–D test scores.

	All athletes (n = 219)
Age at baseline, mean (SD)	20.3 ± 1.4 years
Gender, male, no. (%)	182 (83.1%)
Sport, no. (% of cohort)	
Varsity football	103 (47.0%)
Sprint football	36 (16.4%)
Soccer, women's	25 (11.4%)
Soccer, men's	25 (11.4%)
Basketball, women's	12 (5.5%)
Basketball, men's	18 (8.3%)
Self-reported concussion history	
Concussion (lifetime), no. (%)	57 (26.0%)
Number of concussions among those with prior concussion, median (range)	1 (1–7)
Pre-season K–D test 1, median (range), entire cohort (n = 219)	38.6 s (26.1–58.0)
Pre-season K–D test 2, median (range) (sprint football only, n = 36)	36.1 s (23.4–52.1) P < 0.0001 vs. test 1 [a]
Best pre-season K–D test, median (range) (n = 219)	37.9 s (23.4–58.0)
Pre-season MACE score, median (range) (women's basketball only, n = 12)	29 (26–30) [b]
Post-exercise K–D test, median (range), (men's basketball only, n = 18) [c]	35.0 s (28.3–40.8) P = 0.0003 vs. best pre-season
Post-season K–D test, median (range) (n = 219)	35.1 s (25.5–55.6) [d] P = 0.03 vs. best pre-season
K–D change pre- to post-season, median (range) (n = 219)	−0.69 s (−9.5–11.8) [d]

K–D = King–Devick Test; MACE = Military Acute Concussion Evaluation (nearly identical to Standardized Assessment of Concussion [SAC]).
[a] Comparison of pre-season K–D test 1 vs. 2 in sprint football cohort, Wilcoxon signed-rank test.
[b] MACE score maximum is 30.
[c] Exercise consisted of a 2-hour scrimmage, with K–D testing done immediately afterward under conditions identical to pre-season testing.
[d] Minimal but significant learning effects (post-season K–D score lower [better] than best pre-season score) were noted overall for the cohort; negative numbers for change in K–D score indicate improvement.

4. Discussion

Results of this study of collegiate athletes provide initial evidence in support of the King–Devick (K–D) test is a strong candidate rapid sideline visual screening tool designed to complement other diagnostic assessments for sports-related concussion. Similar to a previous study of boxers and mixed martial arts (MMA) fighters, the K–D test in this cohort showed worsening of scores following concussion with a median increase of 5.9 s. These data suggest that the K–D test appears sensitive to the deleterious effects of concussion on visual tracking. Ongoing follow-up in this study with additional concussion events and different athlete populations will further examine the effectiveness of the K–D test and will determine change values that are clinically significant. Despite the small cohort size (n = 10) for athletes with concussion and sideline K–D testing in this ongoing study, statistical significance was noted between the baseline and sideline scores in this group, likely due to the degree of separation in the average total time scores.

Since detecting early signs of concussion can improve outcomes [15,18,19,21], there is a need for a rapid screening test to assess athletes in the context of appropriate medical evaluation and other measures. The K–D test is based on the time that it takes to perform a rapid number naming test [33,34]. Continued evaluation of assessment tools for management as well as diagnosis of concussion will be critical. The K–D test has the advantage of being a very portable and easily adaptable test for administration on the sidelines. Requiring less than 1–2 min to complete, the K–D test can be given as a series of spiral-bound moisture-proof 6 × 8 inch test cards, or as an application on a tablet computer system. Athletes in the present study used the test cards, but a tablet computer system is under investigation and will allow for substitution of different numbers at the various testing levels. The K–D test does not require athletic trainers or medical professionals to administer. This characteristic as well as the simplicity of the rapid number naming task makes the K–D test a potentially useful tool for high school and youth sports in addition to collegiate and professional sports.

The K–D test captures eye movements, attention, language, and other areas that correlate with suboptimal brain function [33–35]. The brainstem, cerebellum, and cerebral cortex are all involved in these processes. The Standardized Assessment of Concussion (SAC) is used as a sideline measure of cognitive function, but does not assess eye movements or brainstem function [14,37]. While the SAC was examined for validity, those studies were performed greater than 10 years ago using previous definitions of concussion that required an alteration of mental status. While changes in mental status are critical in accessing concussion, a multi-dimensional approach to assessing brain function during the acute injury stage allows clinicians to make

Table 2
The effects of concussion during the playing season on K–D scores.

	Athletes with no concussion during playing season (n = 206)	Athletes with concussion during playing season (n = 10 tested on sidelines)
Age at baseline, mean (SD)	20.3 ± 1.4 years	20.3 ± 1.0 years
Gender, male, no. (%)	170 (82.5%)	9 (90.0%)
Sport, no. (% of cohort)		
Varsity football		5 (50.0%)
Sprint football		1 (10.4%)
Soccer, women's		
Soccer, men's		2 (20.0%)
Basketball, women's		1 (10.0%)
Basketball, men's		1 (10.0%)
Self-reported concussion history		
Concussion (lifetime, %)	52 (25.2%)	4 (40.0%)
Number of concussions among those with prior concussion, no., median (range)	1 (1–7)	1 (1–2)
Best pre-season K–D test, median (range)	38.6 s (23.4–58.0)	37.0 s (32.5–53.4)
Sideline K–D test, median (range)	–	46.9 s (32.7–64.1) [a] P = 0.009 vs. best pre-season
K–D change pre-season to sideline test, median (range)	–	5.9 s (−0.5–28.1) [b]
Post-season K–D test, median (range)	35.1 s (25.0–55.6) [a] P = 0.01 vs. best pre-season	36.0 s (34.5–42.1) [a] P = 0.59 vs. best pre-season
K–D change pre- to post-season, median (range)	−0.72 s (−9.5–11.8) [a]	4.0 s (1.9–6.2) [a]

K–D = King–Devick Test.
[a] Comparison of sideline or post-season vs. best pre-season K–D scores, Wilcoxon signed-rank test.
[b] Significant worsening from pre-season baseline was noted for sideline K–D scores in athletes with concussion during the season; positive numbers for change in K–D score indicate worsening.

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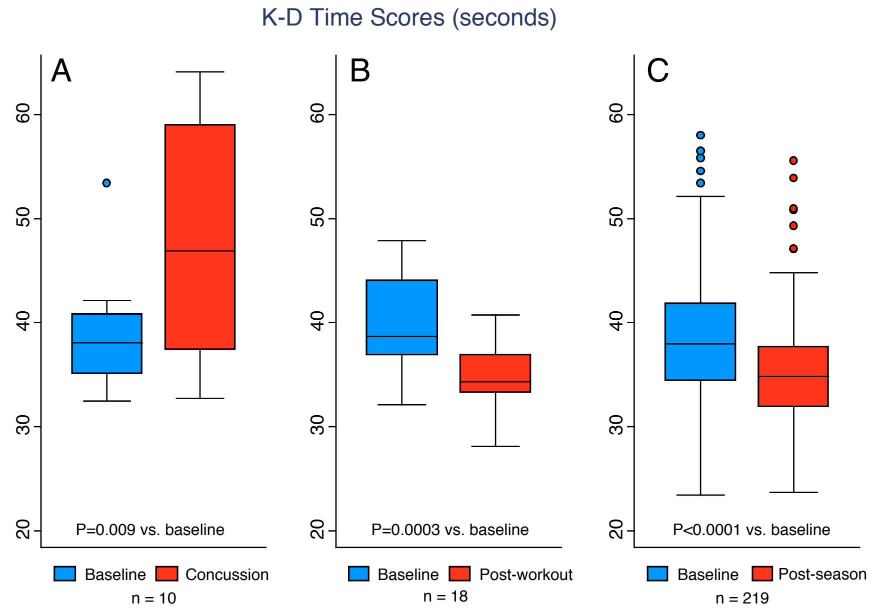

Fig. 2. Box plots show the median K–D scores for (A) baseline and sideline testing for athletes with concussion during the playing season (n = 10) demonstrating worsening of scores, (B) baseline and post-scrimmage (post-workout) testing for men's basketball players (n = 18) showing improvement of scores following 2 h of vigorous exercise, and (C) baseline and post-season testing for all athletes (n = 219) demonstrating improvement of scores likely consistent with learning effects. The lines in the box represent the medians, and boxes delineate the interquartile range (25th to 75th percentiles). Whiskers represent the range of observations minus outliers; the circles represent outliers. P values are based on Wilcoxon signed-rank tests comparing sideline and scrimmage vs. baseline testing.

the most informed decisions [19,21]. The K–D test is likely complementary to the SAC and to other tools designed for sideline diagnosis of concussion, such as the Balance Error Scoring System (BESS) [39,40]. Both the SAC and the BESS tests are part of the SCAT 2 battery of tests. It is therefore possible that a composite of these rapid tests would create a performance measure providing objective and easy assessment of athletes with suspected concussion. However, the validity and the reliability of these tests need to be examined separately as well as part of a composite of measures for concussion, and it must be emphasized that no single test can at this time be used to diagnose or manage concussion. Medical evaluation and opinion should always be sought in these circumstances.

In the absence of concussion, this study as well as a previous investigation of boxers and MMA fighters revealed that the K–D test has learning effects associated with repeated testing [33]. This is a feature common to many timed tests, or performance measures. As such, many athletes improve (decrease) their K–D time score over the course of two testing sessions or between pre- and post-season measurements. Participants in the boxing and MMA study without concussion improved by a median of 1.9 s from pre- to post-fight [33], while athletes in our collegiate study improved their scores by 2.5 s when tested twice within a 15 minute interval. Pre- to post-season changes were 0.72 s in the direction of improvement for athletes who did not have a concussion. These findings are consistent with learning effects for the K–D test under optimal conditions, emphasizing the fact that worsening of scores is likely to be a reliable indicator that athletes should be evaluated further for concussion. Importantly, basketball players in our cohort who were tested immediately following an intense two-hour scrimmage did not demonstrate worsening of K–D time scores from baseline, but instead showed a 3.6 second improvement on average. Thus, there was no evidence that fatigue had a negative effect on K–D performance in this pilot cohort. In both our boxing and collegiate athletes, exercise was associated with a stable or improved scoring time. Follow-up scores for athletes with concussion improved to baseline one week following the event, consistent with other studies demonstrating clinical improvement in that time frame.

In addition to the time required to complete the three test cards that comprise the K–D test, the number of errors made during the rapid number naming task is also recorded. In our cohort the numbers of errors were few. Among the athletes with concussion, one made four errors and two others made one error on sideline testing. Errors in two of these cases were associated with a lack of substantial time score worsening, suggesting that there may be a tradeoff of accuracy for increased time to complete the K–D test in some concussed athletes. Further study will be necessary to examine how the number of errors, particularly when different from baseline, relate to the time score on sideline K–D testing in the setting of concussion. For example, a small amount of time, such as 0.5 s, could be added to the total time score for each error. Since it takes the average collegiate reader about 0.35 s to name each number, a 0.5-second penalty would likely be a fair correction factor to account for the tradeoff of accuracy for time.

Prevention and proper management of concussions is important for athletes and all persons sustaining head injury. Retired athletes with a history of concussion have been found to exhibit greater memory loss, and a greater prevalence of mild cognitive impairment (MCI) compared with those athletes who have not had a concussion [18]. Furthermore, studies of retired athletes show correlations between depression and concussion [19]. Many athletes who had been concussed also reported physical limitations that interfered with daily life [19]. Rugby athletes with three or more concussions had worse performance in visual motor and visual processing speeds compared to controls, indicating that these two measures may be sensitive to the long-term effects of concussion [22]. Given the potentially devastating consequences of concussion, and the desire of young athletes and coaches for the athlete's immediate return to play, it is necessary to have an objective rapid test that can be used to complement other diagnostic assessments. If a player performs worse on the K–D test compared to baseline at the time of suspected concussion, then this test may be one tool to help coaches and trainers with return to play decisions by providing objective evidence from a timed test to add to the clinical judgment of medical professionals and trainers.

A growing number of visits to the emergency room with concussion indicate the need for effective measurement tools [12]. Determining when a player is ready to return to play is complicated,

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and often it is unclear who is responsible for this decision [12]. An important part of improving outcomes is through the education of athletes, coaches, parents, trainers, and physicians regarding concussion and return-to-play [9]. Ongoing enrollment and follow-up in this cohort of collegiate athletes will allow for refinement of study design features, including baseline testing on the sidelines, testing in the setting of post-game fatigue on a larger scale, and testing of athletes without concussion during the game or practice period as controls. The time period for recovery of K–D scores to baseline following concussion will also need to be investigated. In conjunction with other sideline tests and standard medical assessment, the K–D test addresses the need for a quick, reliable test that can accurately identify concussion and thus reduces the potentially devastating effects of second impact syndrome and recurrent neurological injury.

Despite increasing interest in testing for sports-related concussion, sideline screening tools, including those now in widespread use, have not been validated using contemporary definitions of concussion. Our study provides an initial step towards validation of the K–D test as a rapid sideline screening tool for concussion. As with any new diagnostic test, a series of collaborative studies over time will be needed to ensure that the reliability, validity, and generalizability of the K–D test. The focus on sports-related concussion has emphasized the need to develop evidence based protocols for the diagnosis and management of concussion. Further studies will include testing of athletes during games/practice who do not have a concussion but who play similar positions; these athletes would constitute a more rigorous control group with which to compare K–D scores of concussed athletes. The K–D test and other similar tests will need to be validated in a variety of sports either as a stand-alone measure or as part of a composite. The reliability of such tests will also need to be examined across various age groups, including athletes in contact sports at the youth, high school, collegiate and professional levels.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at doi:10.1016/j.jns.2011.07.039.

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