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

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ABSTRACT

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

Methods: Fifty-four athletes (M=11.7 years, SD=2.89, range=6-17 years) participating in the 2014 Amateur Athletic Union (AAU) Junior Olympic Games were baseline tested with the K-D test at the beginning of a sports vision screening and then again at the conclusion of the screening with approximately 30 minutes between the baseline test administrations. Baseline test administrations determined baseline scores as the fastest error-free time of two consecutive trials.

Results: A high level of test-retest reliability was observed between two Baseline Trials (ICC=0.90, 95% CI [0.85-0.95]). Similarly, there was a high test-retest reliability between the first Baseline Score (the better 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). There was no significant difference in K-D performance between genders ($p=0.61$).

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

Keywords: concussion, King-Devick, mild traumatic brain injury, saccades, sports vision, visual motor coordination

Introduction

Increasing public interest surrounds sports-related concussion due in part to recent studies suggesting a link between repetitive head trauma and long-term neurological sequelae.[1,2] As concussed athletes are at higher risk for repeated subsequent concussion,[3] recognition of initial concussive injury has become the priority. The identification of a rapid yet simple performance measure to help coaches, parents, and medical personnel identify concussion on the sidelines, particularly in youth sports, is critical. Young athletes are more vulnerable to concussive injury. The immaturity of the central nervous system at this age results in incomplete myelination of the brain tissue, putting the developing brain at greater risk for injury.[4,5] Additionally, when compared to adults, youth and adolescent athletes have a larger head-to-body ratio, reduced development of neck and shoulder musculature, and differences in cerebral blood volume and blood flow during injury. This leads to more widespread and prolonged cerebral swelling and increased metabolic sensitivities following head injury, resulting in more prolonged and severe symptoms.[4,6]

Professional and collegiate athletic programs have begun to place neurologists, neurosurgeons, athletic trainers, and team physicians on the sidelines for the assessment of head injuries sustained during play. In stark contrast, the majority of U.S. high schools do not have access to athletic training staff,[7] and there is an even greater lack of medical personnel at the youth and amateur sports level. This marked disparity underscores the need for a predictive sideline test that can be performed by laypersons to help objectively determine concussive injury and remove an athlete from play, particularly since athletes often under-report their symptoms.[8] The King-Devick (K-D) test is composed of a demonstration card and three test cards that increase in difficulty. The K-D test of rapid number naming requires vision, eye movements (saccadic, accommodative, and vergence), concentration, language function, and attention to perform, and it has been shown to reflect suboptimal brain function as a result of concussion,[9-15] multiple sclerosis,[16] Parkinson's disease,[17] hypoxia,[18] and extreme sleep deprivation.[19]

Recent studies highlight the utility of the K-D test on the sidelines to detect both concussive as well as sub-concussive injury in high school,[20,21] collegiate,[3,9,20,22] and professional[10,11,13] level athletes. The K-D test demonstrates high test-retest reliability with published intraclass correlation coefficients of 0.92,[20] 0.95 [95% CI 0.85-1.05],[10] and 0.97 [95% CI 0.90-1.0].[9] The purpose of this study is to examine the test-retest reliability of the K-D test further, particularly in youth athletes. Unlike previous studies carried out, this study included youth athletes starting at the age of six years.

Methods

Participants

Athletes participating in the 2014 Amateur Athletic Union (AAU) Junior Olympic Games were recruited to participate in a sports vision screening. Consent and assent were obtained for all participants. The Illinois College of Optometry/Illinois Eye Institute Institutional Review Board approved all procedures in the study.

The King-Devick test

The King-Devick (K-D) test of rapid number naming requires vision, eye movements, concentration, language, and attention.[10,11] The K-D test comprises a demonstration card and three test cards that become progressively more demanding due to changes in vertical spacing between lines.[23] The athlete is required to read numbers on each card from left to right and top to bottom as quickly as possible without making any errors. Performing the task requires the coordination of multiple cortical and subcortical pathways of the brain and brain stem, which are common areas of impairment following concussion.[11,24] The K-D test takes approximately 2 minutes to complete and can be administered by non-physician observers on the sidelines, such as coaches or parents of sports participants.[12] The K-D test is available as a spiral-bound moisture-proof set of 15x20 cm test cards or as a standard sized iPad application with accompanying mobile administrator scoring application. The physical spiral-bound tests were utilized in this investigation.

Procedures

Participants were baseline tested with the K-D test using the standardized baseline testing procedures, which require two trials, with the faster of the two trials without errors constituting the Baseline Score. Athletes ages 10 years and older were tested with all K-D test cards (I, II, III). Athletes ages 8 and 9 were tested with test cards I and II, and athletes ages 7 and under were tested with only test card I. To examine test-retest reliability of the K-D test, baseline testing was completed at the beginning of the vision screening and then repeated after approximately 30 minutes. A total of two Baseline Scores were determined, and four Baseline Trials were completed by each athlete (Trials 1 and 2 during initial testing, Trials 3 and 4 during retest). The athlete was wearing his/her best near prescription lenses. All K-D testing was performed in a noisy gymnasium, with multiple athletes being tested simultaneously. If there were errors in Baseline Trials, the data was not used for statistical analysis. The K-D test administrators were optometry school students from the Illinois College of Optometry and the Indiana University School of Optometry who were trained to use the K-D test through standard instructions included in the test.

Statistical Analysis

Data were analyzed using STATA 12.0 (Stata Corp, College Station, TX, USA). Descriptive statistics were used to summarize the continuous measures of the cohort. To compare differences, between-group t-tests were used. Intraclass correlation coefficients (ICC) were used to examine test-retest agreement between the K-D Baseline Trials, as well as between test and retest Baseline Scores. Linear regression models were used to examine correlations between age and K-D test performance.

Results

Fifty-four athletes (M=11.7 years, SD=2.89, Range=6-17 years) completed the baseline testing for this study. Characteristics of the cohort and baseline testing results are summarized in Table 1. Thirty-one (57%) athletes were male. Analysis using the two-sample t-test with equal variances concluded that there was no significant difference in K-D performance between genders ($p=0.61$, t-test). Athletes represented a variety of Junior Olympic sports [power lifting (n=2), baseball (n=4), jump rope (n=15), cup stacking (n=7), basketball (n=2), gymnastics (n=11), hockey (n=1), tennis (n=1), and other (n=11)].

Subsequent K-D test administrations showed slightly improved (lower) times across Trials 1 through 4, with high test-retest reliability measures between trials of baseline administrations (Table 1, Figure 1; Trial 1 vs. Trial 2, ICC=0.89, 95% CI [0.85-0.95]; Trial 3 vs. Trial 4, ICC=0.95, 95% CI [0.92-0.98]). Retest K-D Baseline Score 2 times, were slightly lower (better) than initial Baseline Score 1 times, which is consistent with previous studies and likely due to a learning effect. The ICC for K-D Baseline Scores similarly indicated a high degree of test-retest reliability (Table 1, Figure 2; ICC =0.93, 95% CI [0.89-0.97]).

Performance on the K-D test correlated with the age of the athletes, with older athletes demonstrating improved K-D scores (lower time). On average, for every 1 year increase in

Table 1. Characteristics of Study Participants & King-Devick Test Scores

	All Participants (n=54)
Age (years), *mean(range)*	11.7 (6-17)
Male, n (%)	31 (57%)
Baseline Trial 1 (sec), *mean(SD)*	49.5 (±13.3)
Baseline Trial 2 (sec), *mean(SD)*	47.2 (±13.0)
ICC (95%CI), Baseline 1 Trial 1 vs. 2	0.89 (0.85-0.95)
Baseline Score 1	46.3 (±12.2)
Baseline Trial 3 (sec), *mean(SD)*	44.3 (±12.0)
Baseline Trial 4 (sec), *mean(SD)*	44.1 (±11.3)
ICC (95%CI), Baseline 2 Trial 1 vs. 2	0.95 (0.92-0.98)
Baseline Score 2	43.1 (±11.4)
ICC (95%CI), Baseline Score 1 vs. 2	0.93 (0.89-0.96)

Abbreviations: ICC=intraclass correlation coefficient, CI=confidence interval

test. These areas are also susceptible to impairment following concussion.[24,29]

Sports-related concussion has been a topic of attention in medical and lay literature due to its short- and long-term neurologic symptoms. Due to the differences in symptoms among individual athletes who present with concussion, sports-related concussion is a very complex diagnostic and management problem for the medical team with respect to determination of return-to-play guidelines.[30] Individuals who have suffered mild traumatic brain injuries often report a wide array of physical, cognitive, and emotional/behavioral symptoms referred to as post-concussion syndrome. Some of the symptoms experienced include headache, decreased concentration, visual disturbances, fatigue, sensitivity to noise, depression, and anxiety. Although these symptoms often last for about a month, they can also persist for months to years and cause long-term disability.[31] Long-term sequelae and disability can arise from neuropathology resembling Alzheimer's disease. Chronic traumatic encephalopathy (CTE) is a progressive neurodegeneration that is clinically associated with memory disturbances, behavioral and personality change, Parkinsonism, and speech and gait abnormalities.[32,33] At this time, CTE can only be diagnosed postmortem. The easiest way to decrease the incidence of CTE is to decrease exposure to repetitive head injury.[33]

As youth athletes are more vulnerable to concussive injury due to the immaturity of the developing central nervous system, larger head-to-body ratio, reduced development of neck and shoulder musculature, and differences in cerebral blood flood and volume,[4-6] it is imperative to incorporate an

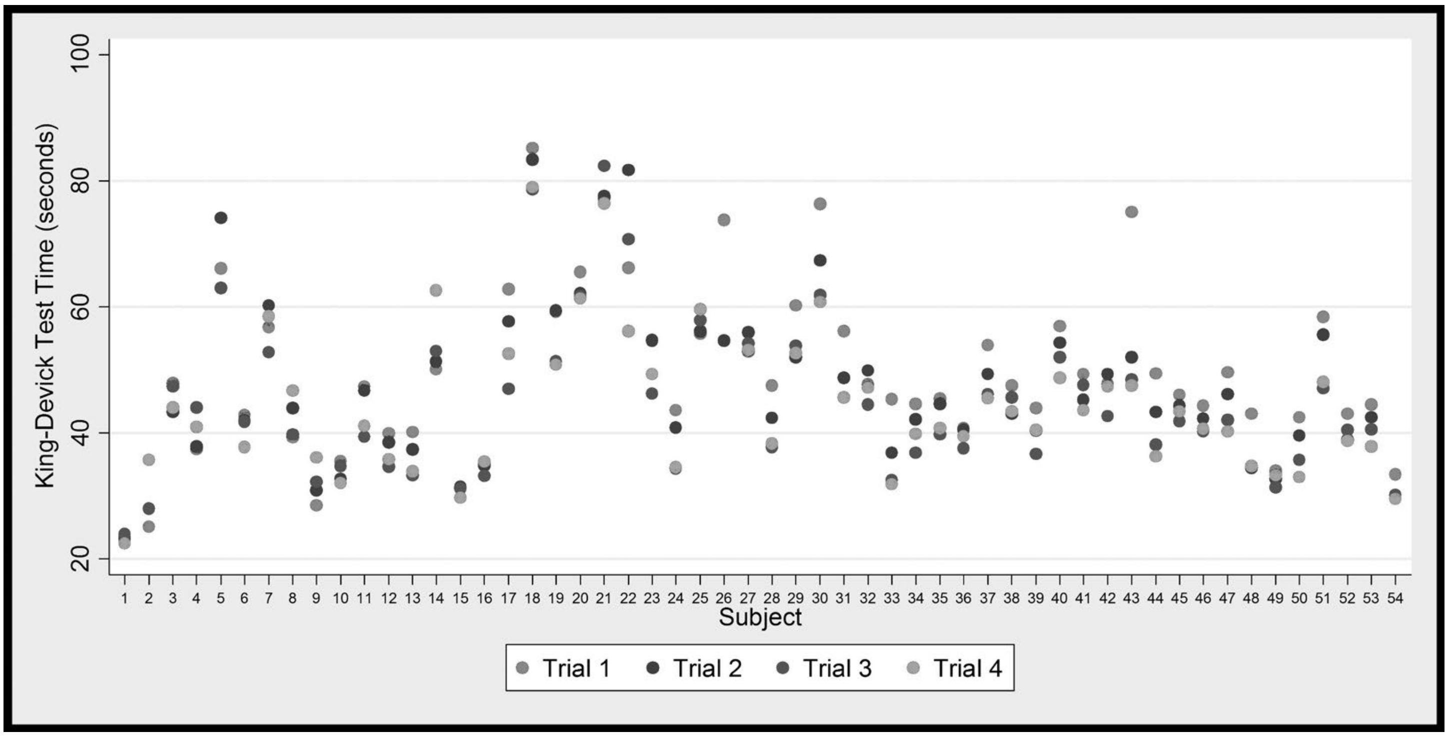

Figure 1. *K-D Baseline Trial Scores. Scatter plots show the distributions of the four K-D Baseline Trial scores across the 54 athletes. A high level of test-retest reliability is observed between Baseline Trial 1 and 2 (ICC=0.90, [95% CI 0.85-0.95]) and between Baseline Trial 3 and 4 (ICC=0.95 [95% CI 0.92-0.98]).*

age, there was a corresponding decrease (improvement) in K-D score of 3.7 seconds (95% CI [2.5-5.0], $p<0.001$, R2 = 0.50, linear regression; Figure 3).

Discussion

It is widely known that vision and eye movements are frequently affected following brain trauma, including latency and accuracy of eye movements.[25-28] As such, changes in eye movement function may serve as a predictor of post-concussion syndrome.[28] The K-D test requires visual processing, eye movements (including saccadic, vergence, and accommodative systems), attention, and language function[29] as it is based on measurement of the speed of rapid number naming. Coordination of the brainstem, cerebellum, and cerebral cortex is necessary for these systems to integrate when performing this

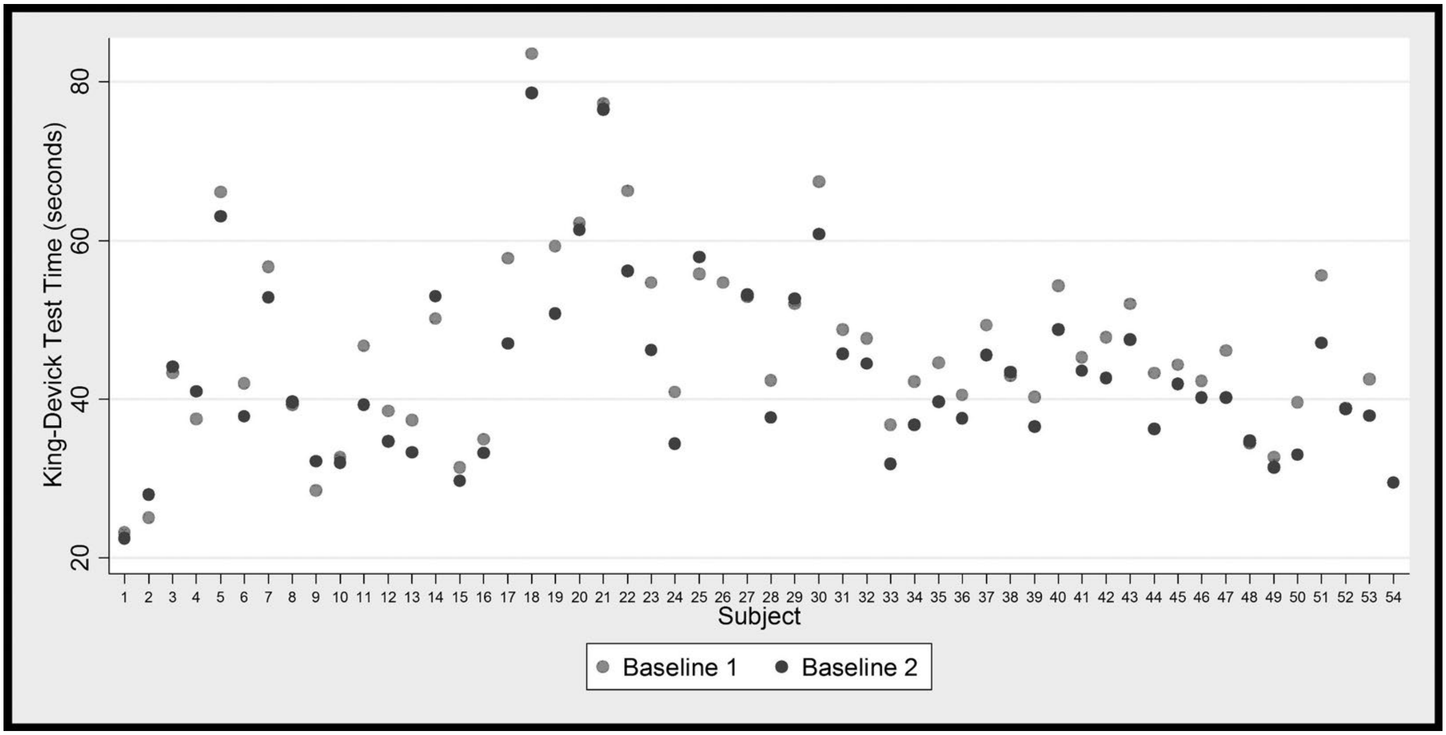

***Figure 2.** K-D Baseline Scores. Scatter plots show the distributions of the first K-D Baseline Score (the better of two trials) and the retest K-D Baseline Score across the 54 athletes. A high level of test-retest reliability is observed between Baseline Scores (ICC=0.93 [95% CI 0.89-0.96]).*

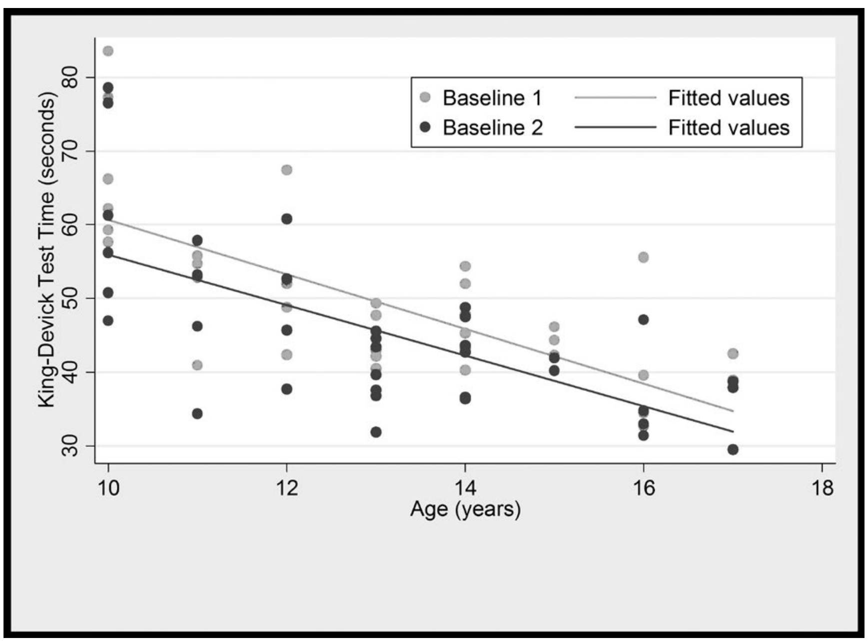

***Figure 3.** Relation of Athlete Age and K-D Test Time. For athletes who completed all test cards, there was a correlation between age and K-D test time. Improved K-D scores (lower times) were associated with older athletes. On average, for every 1 year increase in age, there was a corresponding decrease (improvement) of K-D score of 3.7 seconds ([95% CI 2.5-5.0], p<0.001, R2=0.50, linear regression).*

easy-to-administer predictive sideline test for concussion in this population. Recent studies have demonstrated that the K-D used alone had the ability to identify concussion in 79% of athletes;[20] when added to the Standardized Assessment of Concussion (SAC) and Balance Error Scoring System (BESS), 100% of concussions were identified.[34] In the absence of concussion, there is high test-retest reliability of the K-D test in collegiate and adult populations with reported ICC values ranging from 0.95 to 0.97. Until the results of this study, the test-retest reliability had not been evaluated in the youth population.

The need for sideline rapid assessment of concussion is fundamental to limiting the deleterious effects of repeated head injuries. The majority of athletes are at the youth sports level and not collegiate or professional, which leaves many important decisions to be made by parents and coaches on the sideline. Empowering adults to administer a simple, rapid, yet effective test is paramount to preventing repeated head injuries. The K-D test takes approximately 2 minutes to perform and can be administered by non-physician observers on the sidelines, such as parents of sports participants, athletic trainers, and coaches.

In order for the K-D test to be used effectively over time and to be administered by different testers, such as athletic trainers, the interrater and test-retest reliability of this measure must be assessed. This study showed a high degree of test-retest reliability in elite junior youth athletes (ICC=0.93, 95% CI [0.89-0.97]).

Some neurocognitive concussion evaluations use normative values to enable post-injury comparisons, especially in the absence of baseline data.[35] Normative K-D values were recently reported for Finnish professional ice hockey players[35] and compared to K-D baseline scores in prior studies.

When compared with K-D performance values of Finnish professional ice hockey players, the cohort of National Hockey League professional ice hockey players[11] and collegiate contact sports athletes[9,20] were in the average normative range, whereas boxers and mixed martial arts (MMA) fighters[10] fell in the below-average range, and amateur rugby union[13] and league[14] players were in the unusually low range.[35] The differences in baseline test scores of the different cohorts underscore the need to obtain an annual individualized baseline test score. An individual baseline score enables comparisons to be made post-activity without needing to rely on normative data. The wide range of baseline K-D scores by age found in this study supports a previous recommendation[23] that normative K-D test data should not be used for the sideline detection of concussion.[35]

At the time of data collection for this study, the youth protocol for K-D testing was to use all three cards for children ages 10 and over, cards 1 and 2 for children ages 8 or 9 years old, and card 1 for children ages 7 and under. The third card is the most difficult to complete due to the crowding effect.[23] The most recent guidelines for the administration of the K-D test in a youth population suggest that children aged 9 years or younger may not be able to complete all test cards without errors. If the patient is unable to complete the test cards without errors, the last test card should be eliminated. Thus, there will be a reduced number of test cards for baseline testing, and the same number of test cards should be utilized in the sideline evaluation for comparison. It is also now recommended that patients 9 years of age and younger establish a baseline score every 6 months as K-D Test performance correlates with reading ability and age, particularly in the youth population.

As part of this current evaluation, a sports vision examination was conducted to assess additional visual factors that may play a role in creating visually directed baseline performance data. This examination included the following tests: visual acuity, refraction, ocular health examination, eye dominance, ocular alignment, accommodation, vergence, fixation and saccades, eye-hand coordination, speed of recognition, and distance depth perception. Future investigations will address the role of these factors in attaining a complete visual profile in an athletic population and in determining which factors in the visual system are significant in diagnosing concussion and return-to-play guidelines.

Conclusions

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

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