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Research Article

Agreement of the Spiral-Bound and Computerized Tablet Versions of the King-Devick Test of Rapid Number Naming for Sports Related Concussion

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Abstract

Sports-related concussions are an increasingly recognized public health problem and may have serious neurologic implications for athletes. The vision-based King-Devick (K-D) test of rapid number naming has become an important tool to screen for concussion in athletes on the sidelines. In recent years there has been a shift towards using a computerized tablet version of the K-D and although there are several studies demonstrating its utility in screening for concussion, there is limited data directly comparing the two versions. Therefore, the purpose of this investigation was to measure levels of agreement and quantify the relative differences in baseline scores between the spiral-bound and computerized tablet versions of the K-D test. We recruited 85 participants into the study and administered both K-D test versions to each participant. There was excellent agreement (ICC=0.92, 95% CI: 0.82, 0.96) and strong linear correlation(r=0.94) between the two versions. However, the tablet version had a significantly longer mean pre-season baseline time compared to the spiral version (52.3 seconds vs. 48.6 seconds, p<0.001, paired t-test). A difference of 3.7 seconds between the two test modalities may be clinically significant since acutely concussed athletes in published studies and meta-analyses show average increases of 4 to 6 seconds in the K-D test time from baseline. Therefore, the two K-D test versions have excellent agreement suggesting that the tablet version should also be good predictor of concussion. However, alternating between the tablet and spiral versions of the K-D test may be inaccurate when screening for concussion during sideline testing.

ABBREVIATIONS

mTBI: Mild Traumatic Brain Injury; TBI: Traumatic Brain Injury; K-D: King-Devick; CT: Computed Tomography; MRI: Magnetic Resonance Imaging; ICC: Intra-Class Correlation Coefficient

INTRODUCTION

Sports-related concussions are relatively common with approximately 1.6-3.8 million occurring every year [1]. From a pathophysiologic perspective, concussion is thought to be caused by rapid acceleration, deceleration, and rotational forces resulting in both physical and physiologic disturbances in the brain [2-6]. However, unlike more severe forms of traumatic brain injury (TBI), the structural changes often are not evident on routine imaging studies including computed tomography (CT) and magnetic resonance imaging (MRI) [4]. Although many symptoms of concussion resolve spontaneously [2,7], it has become increasingly recognized that repetitive mTBI may have serious neurologic consequences. In the short term, concussion places athletes at risk for the rare but serious second impact syndrome [8,9] and in the long term there is increasing evidence that repetitive sub-concussive hits may be related to the development of neurodegenerative disease [10-12]. Thus, there has been a tremendous effort to develop and validate sideline tools that can be used to identify potentially concussed athletes.

One such tool is the King-Devick (K-D) test, a vision-based rapid number naming test that utilizes three test cards with variations in spacing between numbers to evaluate visual tracking; this task requires saccades as well as other eye movements such as convergence. Vision is involved in a large proportion of the brains pathways [13] making visual testing a high-yield system for detection of neurological dysfunction. Additionally, after concussion, visual complaints are common and deficits in eye movements have been clearly demonstrated [14,15]. Therefore, it is not surprising that adding vision to sideline testing has been shown to improve detection of concussion when combined with other tests of cognition and balance [16,17]. The King-Devick test has been utilized for over 30 years as an indicator for ocular motor inefficiencies in patients with dyslexia [18], and has demonstrated utility in screening for concussion in athletes in numerous studies over the past 5 years. In a recent comprehensive meta-analysis, the K-D test alone was shown to have good sensitivity (86%) and specificity (90%) in detecting concussed athletes [18]. Furthermore, the K-D test demonstrates excellent inter-rater [19] and test-retest reliability [20]. The K-D test has been shown to be useful in detecting concussed athletes during sideline screening in a wide variety of sports including hockey, lacrosse, soccer, mixed martial arts, boxing, rugby and football [16,20-24]. Baseline and post-concussion testing has been performed successfully in a variety of sideline and locker room settings (inherently noisy), with consistency of scores across these studies in the recent meta-analysis [19]. Furthermore, exercise and athletic competition alone have been consistently shown not to worsen K-D scores from baseline [16,19,22-24].

The K-D test is also available as an application for use with computerized tablets, and in recent years there has been a shift towards using this electronic version. Although, the newer computerized version of the K-D test has been proven useful in detecting concussions in several studies [23,24], data comparing the spiral and computerized tablet K-D test in the same individual is limited. In theory, the tablet version differs only by the platform by which the test is being delivered and therefore should have the same test characteristics. However, to our knowledge, a study demonstrating levels of agreement between the spiral-bound and computerized tablet versions of the K-D test has not been performed.

The purpose of this study was to determine inter-test reliability between the tablet and spiral versions of the K-D test by calculating the intra-class correlation coefficient (ICC). Additionally, we quantitated the relative differences in pre-season baseline scores between spiral and tablet versions of K-D, and assessed the overall agreement between the two test modalities.

MATERIALS AND METHODS

Study participants

The study protocols were approved by the Institutional Review Board at New York University School of Medicine. Informed consent, as well as child assent when appropriate, was obtained for all study participants. This was a cross-sectional study with a convenience sampling method. Participants were recruited during sideline testing when group size and staff capabilities made adding the tablet version of the K-D test feasible. Youth and collegiate athletes from Pelham Youth Sports Leagues, Long Island University Athletics and the New York University Athletics were included in the study.

King-Devick (K-D) test

Both the spiral-bound K-D test and computerized tablet K-D test were given to each participant. There were multiple test administrators for both the spiral and tablet versions. Randomization of the order of administration of the two versions was achieved using a random number application that assigned each participant a number 1 through 4. This number corresponded to a pre-determined sequence by which the spiral and tablet versions of the K-D test were administered (Table 1). The tablet K-D test had two different versions available, however only one of the two versions was given to any single participant. Version 1 of the tablet K-D test is identical to the spiral version. Version 2 of the tablet K-D test utilizes a different sequence of numbers, but otherwise has an identical format. An Apple iPad without an anti-glare screen was utilized to administer the tablet version for all participants. All tests were performed in an indoor athletic training room or similar indoor space. Background noise and visual distractions were not controlled for and were noted to vary during testing sessions and across sites. In order to eliminate fatigue as a factor, baseline testing was always performed either prior to practice or on a dedicated sideline testing day.

For the spiral version of the K-D test, participants were instructed to read the numbers aloud quickly and with as few errors as possible. Timing began when the subject began reading the first number of each test card and stopped after the last number of the test card was read. Times and errors for each test card were recorded by the test administrator.

For the tablet version, participants were again instructed to read the numbers aloud quickly and with as few errors as possible. They were allowed to hold the tablet at a comfortable reading distance or place it on the table; however they were instructed not to touch the screen. The test administrator was responsible for changing between the test cards by tapping the tablet screen. The time for each test card started immediately after the test administrator tapped the screen, bringing the participant to the test card. After the participant read the last number, the administrator tapped the screen again to stop the time and switch to a break screen. The participant was allowed to pause between test cards, starting the next card only after notifying the administrator they were ready to begin the next card. The tablet recorded times for each test card based on how much time was spent on the test card screen as stated above, but the test administrator recorded errors for each test card on paper.

For both the spiral and tablet versions, the sequence of three test cards was given twice to each study participant. The baseline K-D test time was determined to be the trial with the fastest total time of all three test cards, regardless of which trial had more errors.

Statistical analyses

Statistical analyses were performed using Stata 14.0 software (Stata Corp, College Station, TX). The intra-class correlation coefficient (ICC) was calculated to assess the agreement between the tablet and spiral versions of the K-D test. The ICC indicates the proportion of the variability in a dataset that is attributable to between-subject differences. Linear regression models were used to determine the correlation between the tablet and spiral versions. Additionally, linear regression models accounting for age were used to determine if tablet K-D baseline time predicted spiral K-D baseline time. Finally, paired t-tests were used to determine if there were significant differences in mean K-D baseline times between the tablet and spiral versions of the K-D test within subjects.

RESULTS AND DISCUSSION

During pre-season baseline testing, 85 players were recruited into the study and tested on both the computerized tablet and spiral-bound versions of the K-D test. In total, 45 subjects were randomized to complete the spiral version of the K-D test first and 40 to take the tablet version first. Each participant was given only one of the two available versions of the tablet K-D test. Overall, 45 participants were administered tablet version 1 and 40 participants were administered tablet version 2.

The average age for participants was 15.7 years, with a range of 7-25 years. There were a higher proportion of male participants (74%). The most common primary sports reported were soccer, hockey and football, representing approximately 76.5% of the sample (Table 2).

There was excellent agreement between the tablet and spiral versions of the K-D test, with intra-class correlation coefficient (ICC) = 0.92 (95% CI 0.83, 0.96). This is indicative that the variability in the dataset is mostly due to differences between participants, rather than between the tablet and spiral versions of the K-D test within participants.

The two test modalities also showed strong linear correlations between scores (r=0.94, $p<0.001$, Figure 1). Linear regression models accounting for age demonstrated that tablet baseline K-D time was a good predictor of spiral baseline K-D time ($p<0.001$, R^2=0.89). As noted in previous studies (16), younger athletes in this cohort showed greater K-D baseline times; this was observed for both the tablet (r=-0.71, $p<0.001$) and spiral (r=-0.74, $p<0.001$) versions (Figure 2). The association between improved K-D times with age has been suggested to be a result of developmental changes in saccadic eye movements and cognition [16]. These changes may be explained by continued myelination throughout childhood, thus increasing the speed of neuronal processing and transmission in all neural pathways including the oculomotor system [25]. Additionally, as the age range of the participants in this study spans from young children to young adults, the variation in age is at least in part contributing to the wide range of baseline K-D times. Although 74% of the participants in the present study were male, no gender differences in K-D baseline scores were noted for this cohort or in a recent meta-analysis of published studies [19].

Table 1: Sequence of K-D test administration determined by random number application.

Random Number Generator	1st Test	2nd Test
1	Spiral	Tablet version 1
2	Spiral	Tablet Version 2
3	Tablet version 1	Spiral
4	Tablet version 2	Spiral

Table 2: Characteristics of participants.

Age (years)	15.7+/- 5.0, range 7-25
Level of Play	37 youth (44%), 48 collegiate (56%)
Male (%)	63 male (74%)
Primary Sport	Soccer 25 (29.4%), Hockey 21 (24.7%), Football 19 (22.4%), Lacrosse 7 (8.2%), Track 7 (8.2%), Baseball 3 (3.5%), Wrestling 1 (1.2%), Basketball 1 (1.2%), Rugby 1 (1.2%)

Interestingly, it was noted that as the K-D baseline time increased, the differences between the tablet and spiral versions also increased. This suggests that for players with slower baseline K-D times, there may be a greater difference between the tablet and spiral versions of the K-D test (Figure 3). This systematic variation in differences between the two versions may be a significant factor that limits feasibility of switching between the two tests modalities during the playing season without establishing a new baseline.

Although the tablet and spiral versions of the K-D demonstrated excellent reliability and strong correlations between scores, mean baseline K-D times for the tablet version were significantly longer than the times for the spiral version (52.3 seconds vs. 48.6 seconds, $p<0.001$, Table 3). However, there were no significant difference between the tablet version 1 and tablet version 2 K-D baseline times (55.7 vs. 48.5, p=0.084, (Table 3).

In a recent meta-analysis, it was shown that there was a mean worsening of K-D time of 4.8 seconds from baseline in concussed athletes [19]. Across published studies, average differences between baseline and post-concussion scores ranged from 4 to 6 seconds. Therefore, the average difference of 3.7 seconds noted in this study between the tablet and spiral versions may have clinical relevance and thus limit the feasibility for using the two K-D versions interchangeably. For example, if the spiral-bound version of the K-D test was used to establish an athlete's pre-season baseline and the tablet version was used during the season to screen for concussion, the athlete may have a longer K-D time but we would not be sure if this was due to concussion or the test modality being used. In contrast, if the baseline was

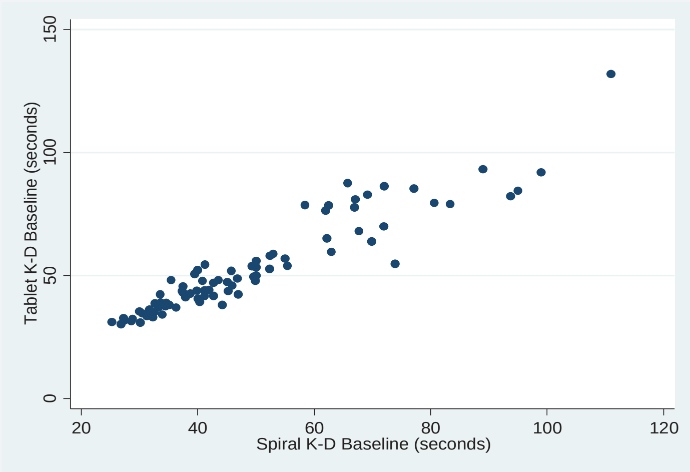

Figure 1 Scatter plot showing a strong linear correlation of tablet K-D baseline and spiral K-D baseline times (r=0.94).

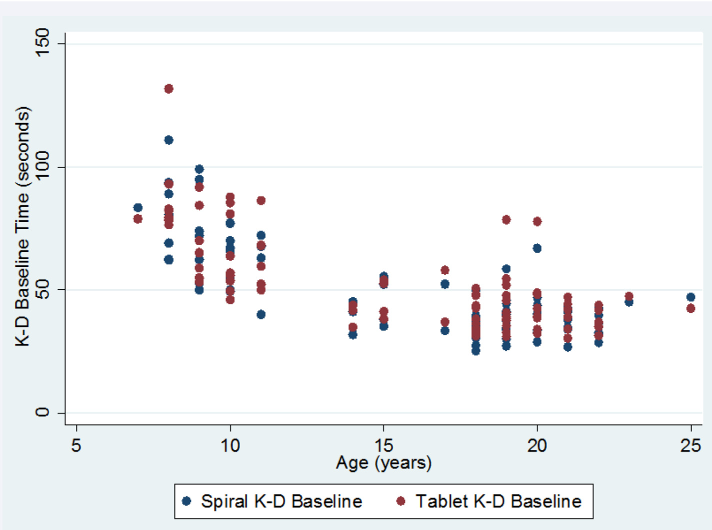

Figure 2 Scatter plot demonstrating the correlation between K-D baseline times and age of participants for both the tablet and spiral versions. There was a similar pattern of correlation of increasing time score with younger age (tablet: r=-0.71 and spiral: r=-0.74) for both test versions.

Table 3: Average K-D pre-season baseline times.

	Sample size (n)	Mean Baseline Time (seconds)	Standard Deviation	Range
K-D Spiral	85	48.6	18.7	25.2-111.0
K-D Tablet	85	52.3	19.3	30.3-131.9
K-D Tablet (V1)	45	55.7	21.4	31.1-131.9
K-D Tablet (V2)	40	48.5	16.0	30.3-87.7

Abbreviations: V1: Version 1 of tablet K-D test; V2: Version 2 of tablet K-D test.

established using the tablet version and the spiral version was used during the season to screen for concussion, we may miss a change from baseline due to the spiral version being inherently faster. This could potentially lead to decreased detection of concussion at the sidelines.

Several possibilities exist to potentially explain differences in test times between the two versions of the K-D test. One consideration is that timing for the spiral bound version begins when the athlete reads the first number on the card, while, for the tablet version, the tester taps the screen to begin timing (this makes the screen appear) before the athlete begins reading. While it seems unlikely that this would result in a full one second delay or more for each card, if true these differences in total could explain the 3-4-second difference in version time for all participants. This difference may be a more important factor for younger

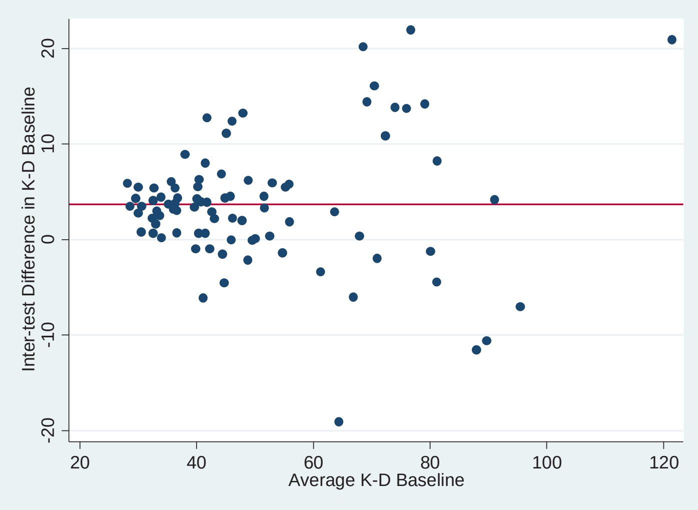

Figure 3 Bland-Altman plot demonstrating differences in K-D baseline time scores between tablet and spiral-bound versions of test across the range of average scores for the two modalities. The inter-test difference in baseline times between the tablet and the spiral versions were plotted against the average baseline times for the tablet and spiral versions for each participant. The average difference between the tablet and spiral version for all participants was 3.7 seconds, represented by the red line. Note the increases in the magnitudes of differences between the two testing methods with increasing average K-D time score.

athletes who may have a more difficult time understanding the instructions given by the test administrator prior to beginning the tablet version of the K-D test. Differences in backlighting, positioning of the tablet vs. spiral bound book for reading, and reflective glare from the tablet screen are also potential factors influencing the differences in test times. Standardization of testing methods between versions, such as having the participant start reading after the examiner taps the spiral bound book, will be one topic of further study for the K-D test of rapid number naming. One limitation of this study was that ambient noise levels and distractions during K-D testing were not controlled, however there were similar levels of background noise at all testing sites. Furthermore, baseline and post-concussion testing has been performed successfully in a variety of sideline and locker room settings (inherently noisy), with consistency of scores across these studies in the recent meta-analysis [19]. In future studies, it may be interesting to compare K-D baseline times across various testing environments.

CONCLUSION

The spiral-bound and computerized tablet versions of the K-D test demonstrate excellent agreement with strong correlations between scores for the two methods. However the relative difference in average K-D baseline times of 3.7 seconds between the two modalities may have clinical implications. In addition, the difference between the spiral and tablet versions appears to be more pronounced in participants with longer baseline K-D times, which tend to be younger athletes. Therefore, while both platforms of the K-D test are good predictors of concussion, caution should be used in switching between the two modalities during the athletic season.

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