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Screening Utility of the King-Devick Test in Mild Cognitive Impairment and Alzheimer's Disease Dementia

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Abstract

The King-Devick Test (K-D) is a 1–2-minute, rapid number naming test, often used to assist with detection of concussion, but also has clinical utility in other neurological conditions (e.g., Parkinson's disease). The K-D involves saccadic eye and other eye movements, and abnormalities thereof may be an early indicator of Alzheimer's disease (AD)-associated cognitive impairment. No study has tested the utility of the K-D in AD and we sought to do so. The sample included 206 (135 controls, 39 MCI, and 32 AD dementia) consecutive subjects from the Boston University Alzheimer's Disease Center registry undergoing their initial annual evaluation between March 2013 and July 2015; the timeframe the K-D was administered. Areas under the receiver operating characteristic (ROC) curves generated from logistic regression models revealed the K-D test distinguished controls from subjects with cognitive impairment (MCI and AD dementia) (AUC=0.72), MCI (AUC=0.71) and AD dementia (AUC=0.74). K-D time scores between 48 and

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52 seconds were associated with high sensitivity (>90.0%) and negative predictive values (>85.0%) for each diagnostic group. The K-D correlated strongly with validated attention, processing speed, and visual scanning tests. The K-D test may be a rapid and simple effective screening tool to detect cognitive impairment associated with AD.

Keywords

Alzheimer's disease; dementia; mild cognitive impairment; saccadic eye movements; King-Devick Test; screening test

INTRODUCTION

The emotional toll and economic burden of Alzheimer's disease (AD) continues to be a global concern as individuals of the baby boomer generation transition into older adulthood. Current estimates indicate 5.3 million Americans are living with AD, and the prevalence is expected to rise exponentially over the next two decades.¹ Alarming, AD is under-diagnosed in nearly half of the American population² and AD pathology may begin up to 20 years prior to the onset of clinical symptoms.^{3,4} These findings highlight the need for sensitive and readily available screening tools that can detect AD in its early stages (e.g., mild cognitive impairment; MCI), particularly as potential disease-modifying therapies become available.

There have been significant gains in the development of biomarkers for the early detection and differential diagnosis of AD, such as positron emission tomography amyloid imaging and lumbar puncture cerebrospinal fluid protein analysis.⁵ However, these tests are invasive, expensive, and time consuming. The use of neuropsychological tests and related paradigms are non-invasive, inexpensive, sensitive to early AD-related cognitive changes⁴ and can reliably differentiate MCI from AD dementia,⁶ and between AD dementia and other neurological disorders.^{7,8} However, neuropsychological testing requires in-depth training to ensure standardized administration and accurate interpretation of findings, and is labor intensive. As such, neuropsychological testing is not typically feasible for use in fast-paced clinical settings, such as primary care. Primary care is indeed a central location for the diagnosis and management of AD, with annual Medicare wellness visits now requiring the addition of cognitive evaluation.^{9,10}

A brief, non-invasive test that is rapid and easy to administer, and is sensitive to detection of MCI and AD dementia would be optimal for primary care or similar settings. Brief cognitive screening tests have been used and refined throughout the years, including the Mini Mental State Examination (MMSE),¹¹ Mini Cognitive Assessment Instrument (Mini-Cog),¹² and Montreal Cognitive Assessment (MoCA).¹³ These tests have adequate sensitivity, but are strongly language dependent and influenced by demographic variables, such as education.^{14,15} As such, their utility in AD can be limited.

Recent work suggests that impaired eye movements may be an early indicator of AD.¹⁶ Saccadic eye movement impairments are one of the most commonly documented forms of oculomotor dysfunction in AD patients,¹⁷⁻¹⁹ and have been recently reported in patients

with the posterior cortical atrophy variant of AD.²⁰ Additional studies have also demonstrated that patients with amnesic MCI exhibit abnormal saccades.^{21,22} These findings raise the possibility that a test of saccadic eye movement may have strong utility in the detection of cognitive impairment, in general, and AD, in particular.

The King-Devick Test (K-D) is a brief, rapid number naming test, that measures processing speed and visual tracking, and performance is dependent on intact saccades and other eye movements. It can be administered by non-physician personnel or even sports parents. It was originally designed to assess reading ability,²³ though its use has extended to the detection of various neurological conditions, including concussion,^{24,25} Parkinson's disease,²⁶ and multiple sclerosis.²⁷ However, to date, no published study has examined the K-D as a screening tool for MCI or AD dementia. The objective of this study was to examine the utility and accuracy of the K-D in a sample of cognitively healthy older adult controls, and individuals with MCI and AD dementia from the Boston University Alzheimer's Disease Center (BU ADC) participant registry. We targeted only participants with AD for the following reasons: (1) AD is the most common cause of dementia and having a tool that can detect AD-related cognitive impairment would be critical for practitioners who encounter patients with AD on a daily occurrence; and (2) although the BU ADC participant registry includes all forms of dementia etiologies, AD is by far the most common, and allows for optimal sample size to test the objective of this study.

MATERIALS AND METHODS

Subjects

The current sample included 206 subjects (135 controls, 39 MCI, and 32 AD dementia) from the BU ADC research registry. The BU ADC is one of 27 centers funded by the National Institute on Aging (NIA) and contributes data to the National Alzheimer's Coordinating Center (NACC). A description of the registry, including participant recruitment and inclusion/exclusion criteria, has been provided elsewhere.^{28–30} Briefly, the BU ADC longitudinally follows older adults with and without cognitive impairment. Inclusion criteria includes community dwelling and English speaking, with adequate hearing and visual acuity. Subjects are excluded for a history of major psychiatric illness (e.g., bipolar disorder, schizophrenia), non-AD neurological illness (e.g., stroke), or head injury with significant loss of consciousness.

As part of the BU ADC registry protocol, participants undergo an annual evaluation comprised of a neurological examination, neuropsychological testing, and measures of functional independence, including tests that make up the NACC Uniform Data Set version 2.0 (UDS).³¹ The K-D was added to the standard annual registry evaluation in March 2013 and the sample included consecutive subjects undergoing their annual evaluation between March 2013 and July 2015; only initial evaluations during which the K-D was administered were included in this study. In addition, only those registry subjects who were deemed to be cognitively healthy (i.e., controls) or received a diagnosis of MCI or AD dementia were included. All participants that the K-D test was administered to were able to complete the test. The BU ADC data collection procedures, including the K-D, were approved by the BU

Medical Center Institutional Review Board. All participants (or their Legally Authorized Representatives) provided written informed consent to participate in the study.

Diagnostic Procedures for the BU ADC Participant Registry

Diagnoses are made at BU ADC multidisciplinary diagnostic consensus conferences, which are comprised of neurologists, neuropsychologists, geriatricians, and geriatric psychiatrists. Consensus diagnosis is adjudicated following presentation and discussion of all examination and test findings (including neuroimaging), as well as social, family, and medical history. Results of the K-D test are not part of the diagnostic process. MCI diagnoses are based on criteria outlined by Winblad et al.³² Of the MCI subjects in the present sample, 11 were amnesic single domain, 12 amnesic multiple domains, 11 non-amnesic single domain, and 5 non-amnesic multiple domains. AD dementia is diagnosed using the National Institute of Neurological and Communicative Disorders and Stroke and Alzheimer's Disease and Related Disorders Association (NINCDS-ADRDA) criteria.³³ Subjects diagnosed with "Probable AD" (i.e., evidence supporting only an AD etiology) or "Possible AD" (i.e., in addition to AD, there is a second etiology that cannot be fully ruled out) were combined. The control group includes subjects who perform within the normal range on all neuropsychological tests and determined to be cognitively normal by the consensus team (n = 135).

Measures

King-Devick (K-D) Test and Other BU ADC Neuropsychological Tests—

Beginning in March 2013, the K-D test was administered at the end of the standard UDS battery. The K-D consists of one demonstration card followed by three consecutive test cards (see Figure 1 in Galletta et al.³⁴). Participants are asked to read single digit numbers printed on the card aloud from left to right, row by row. Each subsequent card increases in difficulty based on changing format and vertical crowding of the numbers. Testing is performed binocularly, with both eyes open. The K-D test score is the total time required, in seconds, to complete the three cards. Higher score is reflective of worse performance. Number of errors committed are also recorded and presented in this study for descriptive purposes. The UDS and other neuropsychological tests examined in the current study are listed in Table 1. All test scores were transformed to z-scores or T-scores using normative data that accounts for demographic variables, such as age, education, gender, and/or race.

Statistical Analyses

One-way analysis of variance (ANOVA) and chi-square analyses examined group differences between controls, MCI, and AD dementia on demographics and cognitive test scores. Bivariate correlations and ANOVA also determined the association between K-D total time scores and demographic characteristics. Binomial logistic regression analyses then examined the ability of the K-D to distinguish between controls versus subjects with cognitive impairment (a combined group of MCI and AD dementia); this combined diagnostic approach was first performed because patients that initially present to the clinic are typically either with or without cognitive impairment, regardless of severity or stage. These same regression analyses also compared each diagnostic group individually (i.e., controls versus MCI; controls versus AD dementia). We did not control for demographic

variables (e.g., age, education, gender) in order to preserve statistical power in the context of the relatively modest sample size. Moreover, there were also no differences across the diagnostic groups (Table 1), and they were largely unrelated to the K-D in this sample (results presented below). Age was also not a significant predictor in the logistic regression analyses (controls versus MCI: p -value=0.2255; controls versus AD dementia: p -value=0.6988).

To further characterize the accuracy of the K-D test, receiver operating characteristic (ROC) curve analyses were performed to calculate the area under the curve (AUC) using the probabilities computed from the logistic regression to distinguish diagnostic categories. Sensitivity and specificity values derived from ROC curve analyses were then used to calculate positive and negative predictive values (PPV and NPV, respectively) to identify optimal cutoff K-D scores for identifying the presence of overall cognitive impairment, and MCI and AD dementia. For the calculation of PPV and NPV, the in-sample prevalence of MCI and AD dementia was used. Finally, bivariate correlations examined the relationship between the K-D total time score and standardized neuropsychological test scores within each diagnostic group. The magnitude of the correlations was interpreted using Cohen's d guidelines: 0.10 = small effect; 0.30 = medium effect; 0.50 = large effect.^{35,36} Lastly, in order to evaluate the utility of the K-D in detecting AD-related cognitive impairment relative to the other neuropsychological measures, ROC curve analyses were again conducted to calculate the AUC for each neuropsychological measure individually and then when combined with K-D test. These ROC curves were performed for controls versus a combined MCI and AD group. Of note, sample size for these analyses was reduced to 196 (131 controls, 36 MCI, and 29 AD dementia) due to missing data across the individual cognitive tests.

RESULTS

Demographic and Cognitive Characteristics

Demographic characteristics and neuropsychological test scores are presented for the three diagnostic groups in Table 1. There were no between group differences on any of the demographic variables. ANOVA showed significant between diagnostic group differences emerged for all of the neuropsychological test measures, $p < 0.001$. Post-hoc Tukey analyses revealed that both the MCI and AD dementia groups performed worse on neuropsychological testing relative to controls, and the MCI subjects exhibited better cognitive test performance than AD dementia subjects.

One-way ANOVA revealed significant differences on the K-D total time score across the diagnostic groups, $F(2,203) = 14.85$, $p < 0.001$, as well as total errors, $F(2,203) = 3.85$, $p = 0.02$. Both MCI and AD dementia subjects performed worse than controls on the K-D. On average, MCI ($p = 0.002$) and AD dementia ($p < 0.001$) subjects were approximately 10 and 16 seconds slower, respectively, relative to controls on the K-D. However, there were no significant differences on the K-D between MCI and AD dementia subjects, $p = 0.33$. Bivariate correlations revealed that K-D time scores were related to age in controls, $p < 0.01$, but not for the MCI ($p = 0.35$) or AD dementia subjects ($p = 0.08$). The magnitude of the

relationship between the K-D and age in controls was also small, $r = 0.27$, $p = 0.002$. There was no K-D and gender or education relationships for any of the diagnostic groups.

Accuracy of the K-D: Logistic Regression and ROC Curve Analyses

Tables 2–4 provide K-D cutoffs and associated sensitivity, specificity, PPV, and NPV for each diagnostic classification. We only present cutoffs associated with high sensitivity ($> 80\%$) to be consistent with the nature of screening instruments; that is, to ensure those with the disease are detected. As such, for all presented cutoffs, specificity and PPV are low. Figure 1 also presents a box plots of K-D Scores across the diagnostic groups.

Controls versus MCI and AD Dementia—The model fit the data well (Hosmer-Lemeshow test = 7.0, $p = 0.5361$), with the K-D making a significant contribution to the prediction of diagnostic classification, OR = 1.05, 95% CI: 1.03, 1.07, $p < 0.001$. ROC curve analyses showed the K-D exhibited an AUC of 0.72, 95% CI: 0.65, 0.80. A total K-D time score between 48 and 52 seconds resulted in a sensitivity > 0.90 and NPV > 0.85 .

Controls versus MCI—The model again fit the data well (Hosmer-Lemeshow test = 4.87, $p = 0.7716$), with the K-D making a significant contribution to the prediction of diagnostic classification, OR = 1.04, 95% CI: 1.02, 1.07, $p = 0.0012$. The K-D exhibited an AUC of 0.71, 95% CI: 0.62, 0.80. A K-D total time score of 48 seconds was associated with a 92.3% sensitivity, and 52 seconds had the highest NPV of 92.0%.

Controls versus AD Dementia—The model fit the data well (Hosmer-Lemeshow test = 9.23, $p = 0.3235$), and the K-D made a significant contribution to the prediction of diagnostic classification, OR = 1.05, 95% CI: 1.02, 1.07, $p = 0.0003$. The K-D exhibited an AUC of 0.74, 95% CI: 0.64, 0.83. A K-D time of 48 and 50 seconds had the highest sensitivity of 93.8 seconds, and 50 seconds had the best NPV of 94.7% (all presented cutoffs had an NPV $> 90\%$).

K-D and Neuropsychological Test Performance

For each diagnostic group, bivariate correlations examined the association between the K-D and standardized neuropsychological test scores assessing attention, processing speed/visual tracking, executive function, memory, and language (Table 5). The K-D was highly correlated with measures of attention, processing speed, and visual tracking across the diagnostic groups, with at least a medium Cohen's d effect size observed for each test; there were large effects for Trail Making Test A and Digit Symbol Coding in MCI and AD dementia (medium effect size for controls). For Trail Making Test B, there was a significant association for controls (albeit small effect) and a trend and medium effect for MCI, but no relationship in AD dementia. In general, the relationship between the K-D with memory and language measures was less robust, as evidenced by inconsistent, small, non-significant, and variable (regarding directionality) effects.

Table 6 provides c -statistic for distinguishing between controls and MCI/AD subjects for each neuropsychological measure individually and when combined with the K-D test. As shown, the K-D performed comparable relative to the other individual measures of attention/

processing speed/executive function. When the K-D was examined in combination with the other measures, the accuracy of detecting cognitive impairment improved, particularly when the K-D was combined with measures that it was not as highly correlated with.

DISCUSSION

Detection of AD is critical to facilitate early intervention, particularly as new therapeutic agents are developed. Brief measures that can be easily administered with minimal training are optimal for fast-paced, high patient volume settings that often encounter older adult patients with cognitive problems. Although an array of brief cognitive screening tools sensitive to AD exist, most are dependent on intact linguistic function and highly influenced by demographic variables. The current study extends the literature by identifying the K-D test, a 1–2 minute, rapid naming task, as an effective measure for identifying cognitive impairment and distinguishing between patients with MCI and AD dementia from healthy older adults.

The current study found the K-D to be an adequate test for the discrimination of healthy older adults from subjects with cognitive impairment, in general. In particular, the K-D accurately discriminated controls from MCI and AD dementia. The K-D performed equally well in detecting MCI and AD dementia from controls and therefore supports its utility in the detection of subtle cognitive impairment, and its application is not limited to severe forms of cognitive impairment. The K-D test evaluates processing speed and visual tracking, and performance on this test is dependent on saccadic eye movement.³⁷ Aging is associated with deterioration of saccadic eye movement³⁸ that may be due to age-related changes of the frontal cortex that mediate saccade generation,³⁸ and such effects may become even more pronounced in AD due to structural alterations of the frontal lobe. Abnormal saccadic eye movement may be an early indicator of AD,¹⁹ and an anti-saccade task has been linked with structural alterations in frontoparietal brain regions in patients with AD, but not in normal elderly.¹⁹ As such, poorer performance on the K-D may be capturing distinct AD-related pathological changes that affect saccadic oculomotor function, but this possibility awaits empirical test.

Although an ideal psychometric instrument yields 100% sensitivity and 100% specificity, the current study presents K-D cutoffs associated only with high sensitivity. A highly sensitive cognitive screening instrument (with the sacrifice of specificity) is critical in order to limit false negatives and ensure identification of all persons with cognitive impairment.³⁹ High sensitivity is also particularly important for clinical settings such as primary care, where the objective is to identify the presence of all forms of cognitive impairment and refer to more specialized services to determine etiology. With high sensitivity there is also typically a high NPV, which is similarly important for the accurate determination that those with a negative test result truly do not have cognitive impairment. In the current study, sensitivity and NPV were largely comparable across the diagnostic groups, with scores on the lower end (i.e., 48 seconds) optimal for sensitivity (>90%), whereas 50 and 52 seconds corresponded to the best NPV (>85%). As expected when sensitivity is favored, the PPV was low for all cutoffs presented. Taken together, the cutoff scores provided may provide some insight into the presence of cognitive impairment and facilitate who may or may not

need to be referred to specialized services for diagnostic and treatment planning purposes. Nevertheless, the reported cutoff scores, NPV, and PPV were all derived from the current sample of BU ADC registry participants and thus are not representative of the general population. Because accuracy partially depends on disease prevalence (i.e., as prevalence increases, PPV increases and NPV decreases), the cutoff scores may need to be adjusted according to the base rates of AD patients at each particular clinical setting, and depending on the clinician's objective and preference. As such, it is critical that future work examine the screening utility of the K-D in a variety of clinical settings to shed further insight into the broad application of the K-D and facilitate appropriate use of cutoff scores. As with all screening measures, it is also encouraged that the K-D be used as supplementary, and not in isolation, to the clinician's evaluation of cognitive impairment.

The K-D is an ideal test for many clinicians and clinical researchers in high patient and research subject volume settings. In addition to being brief and inexpensive, the K-D test requires minimal training to administer or interpret.^{37,40} For example, previous work examining its use in sports-related concussions demonstrates reliable administration of this instrument by non-medically trained laypersons.⁴⁰ Moreover, the K-D was highly correlated with the Digit Symbol Coding and Trail Making Test A, both well-established and validated neuropsychological measures of attention, visual tracking, and processing speed. Given these measures assess mental abilities that overlap with those required for the K-D, our findings provide evidence for good convergent validity for the K-D. We found a statistically significant relationship between Trail Making Test B and the K-D in controls, although there was a trend and a medium effect for MCI. The relationship between saccadic eye movement and executive function appears complicated and in need of further study given past work that shows a relationship between saccadic eye movement and executive function (including set-shifting) in healthy elderly and AD dementia, but generally not in MCI.¹⁹ Finally, the accuracy of the well-validated neuropsychological tests in detecting cognitive impairment improved in the presence of the K-D, highlighting the additive clinical utility of this measure. If replicated in larger samples, the current study highly supports the utility of the K-D test as a screening measure to assist in the detection of AD-related cognitive impairment in the clinic, as well as in large-scale research registry studies.

The current study is not without limitations. We examined cross-sectional data and longitudinal investigation of the K-D in MCI and AD dementia populations is much needed to clarify the predictive validity of this instrument. Specifically, prospective work on the K-D in MCI and AD dementia will allow for investigation of test-retest reliability of this instrument and determine its sensitivity to change. Another important limitation of this study is the modest sample size. Future work that examines the K-D in larger, and more demographically diverse populations along the AD spectrum are needed to confirm our findings, increase the external validity, and establish normative data representative of individuals that span the ages typically assessed for AD-related cognitive impairment. Such work will also be critical to examine the influence of education on K-D performance and to establish normative data across the education spectrum in order to standardize performance and facilitate interpretation of scores. Given the sample size, we also did not examine the K-D across MCI subtypes (e.g., amnesic versus non-amnesic) and this should be the target of future research given patients with amnesic MCI are more likely to develop AD relative to

non-amnestic MCI. Future research should also focus on preclinical AD and on differential diagnosis with other neurodegenerative diseases given potential differences in visual pathways and oculomotor functioning. The current study was without either biomarker support of underlying AD pathophysiological process or neuropathological examination. As such, our sample only represents the likelihood that the subjects have MCI and/or AD dementia that is based on BU ADC diagnostic consensus conferences. Similarly, the sample included participants from a research registry and may thus be demographically and clinically unique from the general population. As an example, although we found an overall lack of K-D effect for age, this could have been due to the demographic nature of the research registry sample and future work is needed to expand and validate our findings in the clinical setting. We only examined the utility of the K-D in participants with AD, the most common cause of dementia. However, research in patients with Parkinson's disease and other neurological conditions suggests that the utility of this instrument likely extends across multiple dementia etiologies and is not specific to AD, and future work in larger, more neurologically diverse samples is needed to test this possibility.

CONCLUSIONS

The K-D is a brief and easily-administered test that may be an effective tool to detect cognitive impairment. If replicated in larger samples, our findings suggest that the K-D may be an appropriate screening measure in fast-past clinical settings, such as primary care physician offices, to assist in the early detection of cognitive impairment and guide referral for more comprehensive evaluation to ultimately facilitate early intervention.

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Figure 1. Box Plot of K-D Scores Across the Diagnostic Groups. Abbreviations: kdtotal = King Devick total time score, MCI = mild cognitive impairment, AD = Alzheimer's disease dementia.

Table 1

Demographics and Neuropsychological Characteristics

	Controls	MCI	AD Dementia	P value
DEMOGRAPHIC				
N	135	39	32	–
Age, mean (SD) years	75.27 (7.35)	77.67 (8.06)	77.59 (7.51)	0.10
Gender, n (%) female	86 (63.7)	18 (46.2)	16 (50.0)	0.09
Race, n (%) Caucasian	115 (85.2)	31 (79.5)	28 (87.5)	0.53
Education, mean (SD) years	16.16 (2.46)	16.23 (2.93)	15.28 (2.80)	0.21
COGNITIVE TEST SCORES, mean (SD)				
N	131	36	29	–
K-D total time (raw) *	59.70 (15.08)	70.19 (15.70)	75.94 (24.44)	<0.001
K-D Errors (raw) *	0.35 (2.20)	0.44 (0.85)	2.50 (9.09)	0.02
MMSE total (raw) *	29.26 (0.91)	27.90 (1.59)	23.16 (3.11)	<0.001
Digit Span total (z score)	0.52 (0.87)	0.02 (0.69)	−0.29 (0.90)	<0.001
Trail Making Test A time (z-score)	0.53 (0.66)	−0.22 (1.08)	−1.18 (2.23)	<0.001
Trail Making Test B time (z-score)	0.41 (0.70)	−0.96 (1.74)	−3.14 (2.40)	<0.001
Digit Symbol Coding total (z-score)	0.47 (0.86)	−0.71 (0.87)	−1.49 (1.00)	<0.001
FAS total (z-score)	0.79 (1.10)	−0.08 (1.14)	−0.76 (1.09)	<0.001
NAB List Learning (LL) Trials 1–3 (T-score)	56.60 (9.51)	42.28 (9.73)	26.90 (7.79)	<0.001
NAB LL Short Delay (T-score)	55.76 (8.76)	42.11 (10.58)	26.21 (6.13)	<0.001
NAB LL Long Delay (T-score)	56.73 (8.38)	42.81 (10.84)	29.90 (6.33)	<0.001
Logical Memory Immediate (z-score)	0.85 (0.88)	−0.22 (1.01)	−1.99 (1.10)	<0.001
Logical Memory Delay (z-score)	0.97 (0.89)	−0.19 (0.99)	−1.99 (0.96)	<0.001
Animals total (z-score)	0.45 (0.95)	−0.36 (0.83)	−1.35 (0.94)	<0.001
Vegetables total (z-score)	0.39 (1.05)	−0.25 (0.90)	−1.35 (0.81)	<0.001
Boston Naming Test (z-score)	0.39 (0.51)	−0.62 (1.10)	−1.68 (1.91)	<0.001

Note.

* N = 206; for significant main effects, there were significant differences across all three diagnostic groups, except for the K-D total, K-D Errors, and Digit Span total, in which MCI and AD dementia did not differ; z-scores and T-scores are demographically adjusted.

Abbreviations: MCI = mild cognitive impairment; AD = Alzheimer's disease; K-D = King-Devick; MMSE = Mini Mental State Examination; NAB = Neuropsychological Assessment Battery

Table 2

K-D Cut Scores for Distinguishing controls from MCI and AD dementia

K-D Score	Sensitivity	Specificity	PPV	NPV
48	94.4	17.0	47.4	85.2
50	91.5	26.7	39.6	85.7
52	90.1	34.1	41.8	86.8
54	84.5	40.0	42.6	83.1
56	83.1	45.9	44.7	83.8

Presented cutoffs represent those with a sensitivity ≥ 80 to be consistent with the nature of screening instruments that favor high sensitivity and sacrifice specificity. The prevalence used for calculation of PPV and NPV is based on the in sample prevalence of MCI and AD dementia.

Abbreviations: K-D = King-Devick; AD = Alzheimer's disease; PPV = positive predictive value; NPV = negative predictive value

Table 3**K-D Cut Scores for Distinguishing Controls from MCI**

K-D Score	Sensitivity	Specificity	PPV	NPV
48	92.3	17.0	24.3	88.5
50	89.7	26.7	26.1	90.0
52	89.7	34.1	28.2	92.0
54	84.6	39.3	28.7	89.8
56	84.6	45.9	31.1	91.2

Presented cutoffs represent those with a sensitivity ≥ 80 to be consistent with the nature of screening instruments that favor high sensitivity and sacrifice specificity. The prevalence used for calculation of PPV and NPV is based on the in sample prevalence of MCI.

Abbreviations: K-D = King-Devick; MCI = mild cognitive impairment; PPV = positive predictive value; NPV = negative predictive value

Table 4

K-D Cut Scores for Distinguishing controls from AD dementia

K-D Score	Sensitivity	Specificity	PPV	NPV
48	93.8	17.0	21.1	92.0
50	93.8	26.7	23.3	94.7
52	87.5	34.1	23.9	92.0
54	84.4	40.0	25.0	91.5
56	81.3	45.9	26.3	91.2

Presented cutoffs represent those with a sensitivity ≥ 80 to be consistent with the nature of screening instruments that favor high sensitivity and sacrifice specificity. The prevalence used for calculation of PPV and NPV is based on the in sample prevalence of AD dementia.

Abbreviations: K-D = King-Devick; AD = Alzheimer's disease; PPV = positive predictive value; NPV = negative predictive value

Table 5

Bivariate Correlations Between the King-Devick and Standardized Neuropsychological Test Scores

	Controls (N = 131)	MCI (N = 36)	AD Dementia (N = 29)
	K-D Time Score	K-D Time Score	K-D Time Score
ATTENTION/PROCESSING SPEED/EXECUTIVE FUNCTION			
Digit Span Total	−0.37 ***	−0.34 *	−0.06
Trail Making Test Part A Time	−0.29 ***	−0.47 **	−0.58 ***
Trail Making Test Part B Time	−0.27 **	−0.31	−0.11
Digit Symbol Coding	−0.46 ***	−0.64 ***	−0.55 **
FAS	−0.24 **	−0.33 *	−0.21
MEMORY			
Logical Memory Immediate	−0.04	0.32	−0.26
Logical Memory Delay	−0.03	0.23	−0.13
NAB List Learning	−0.11	0.46 **	−0.29
NAB Short Delay	−0.07	0.28	−0.13
NAB Long Delay	−0.11	0.37 *	0.07
LANGUAGE			
Animal Fluency	−0.22 *	−0.15	−0.17
Vegetable Fluency	−0.13	−0.24	−0.04
Boston Naming Test	0.04	0.13	−0.21

Note.

*
p < 0.05;**
p < 0.01;***
p < 0.001; Abbreviations: MCI = Mild Cognitive Impairment; AD = Alzheimer's disease; K-D = King-Devick; NAB = Neuropsychological Assessment Battery

Table 6

C-statistic for discriminating between controls vs MCI/AD for neuropsychological scores individually and combined with K-D score

	Individual	Combined with the K-D
	c-statistic	c-statistic
K-D Total	0.72	
ATTENTION/PROCESSING SPEED/EXECUTIVE FUNCTION		
Digit Span Total	0.71	0.75
Trail Making Test Part A Time	0.76	0.78
Trail Making Test Part B Time	0.86	0.86
Digit Symbol Coding	0.68	0.73
FAS	0.29	0.74
MEMORY		
Logical Memory Immediate	0.87	0.90
Logical Memory Delay	0.88	0.91
NAB List Learning Trials 1-3	0.92	0.94
NAB LL Short Delay	0.91	0.94
NAB LL Long Delay	0.91	0.94
LANGUAGE		
Animal Fluency	0.83	0.84
Vegetable Fluency	0.79	0.82
Boston Naming Test	0.83	0.87