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Relationship Between the King-Devick Test and Commonly Used Concussion Tests at Baseline

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Context: Comprehensive assessments are recommended to evaluate sport-related concussion (SRC). The degree to which the King-Devick (KD) test adds novel information to an SRC evaluation is unknown.

Objective: To describe relationships at baseline among the KD and other SRC assessments and explore whether the KD provides unique information to a multimodal baseline concussion assessment.

Design: Cross-sectional study.

Setting: Five National Collegiate Athletic Association institutions participating in the Concussion Assessment, Research and Education (CARE) Consortium.

Patients or Other Participants: National Collegiate Athletic Association student-athletes (N = 2258, age = 20 ± 1.5 years, 53.0% male, 68.9% white) in 11 men's and 13 women's sports.

Main Outcome Measure(s): Participants completed baseline assessments on the KD and (1) the Symptom Inventory of the Sport Concussion Assessment Tool–3rd edition, (2) the Brief Symptom Inventory-18, (3) the Balance Error Scoring System, (4) the Standardized Assessment of Concussion (SAC), (5) the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) test battery, and (6) the Vestibular/Ocular Motor Screening tool during their first year in CARE. Correlation coefficients between the KD and the 6 other concussion assessments in isolation were determined. Assessments with ρ magnitude >0.1 were included in a multivariate linear regression analysis to evaluate their relative association with the KD.

Results: Scores for SAC concentration, ImPACT visual motor speed, and ImPACT reaction time were correlated with the KD ($\rho = -0.216$, -0.276, and 0.164, respectively) and were thus included in the regression model, which explained 16.8% of the variance in baseline KD time ($P < .001$, Cohen $f^2 = 0.20$). Better SAC concentration score ($\beta = -.174$, $P < .001$), ImPACT visual motor speed ($\beta = -.205$, $P < .001$), and ImPACT reaction time ($\beta = .056$, $P = .020$) were associated with faster baseline KD performance, but the effect sizes were small.

Conclusions: Better performance on cognitive measures involving concentration, visual motor speed, and reaction time was weakly associated with better baseline KD performance. Symptoms, psychological distress, balance, and vestibular-oculomotor provocation were unrelated to KD performance at baseline. The findings indicate limited overlap at baseline among the CARE SRC assessments and the KD.

Key Words: oculomotor evaluation, saccades, rapid number naming, symptoms, cognition, balance, vestibular system

Key Points

- The King-Devick (KD) test was only weakly associated with concentration, visual motor speed, and reaction time at baseline.
- At baseline, limited overlap occurred between the KD and commonly used sport-related concussion assessments.
- The KD may augment current multimodal baseline concussion assessments. However, future researchers should explore these relationships in the postinjury setting.

Sport-related concussions (SRCs) are common, with an estimated 1.6 to 3.8 million each year in the United States resulting from sports and recreational activities.[1] Sport-related concussions typically result in clinical symptoms such as dizziness and headache and may lead to impaired balance,[2] cognitive,[3] and vestibular[4] function. Current guidelines[5–7] advocate for a comprehensive approach to evaluating patients with this injury, which may involve baseline assessments to measure preinjury-to-postinjury changes in symptoms and function. Decisions regarding which tests to include are based on institutional requirements, clinical standards of care, financial cost, and the time and available resources required to administer the assessments. As a best practice, the National Collegiate Athletic Association (NCAA)[5] recommends that member institutions perform baseline concussion assessments containing (1) personal concussion and brain-injury history, (2) concussion-related symptom evaluation, (3) cognitive assessment, and (4) balance evaluation. Institutions may perform additional testing at their discretion. Ideally, an additional assessment should increase the ability to detect and manage SRC by evaluating different domains or modes of function, thereby providing unique information with limited overlap.

Vision-based measures, referred to as tests of *oculomotor function*, are emerging assessments for patients with concussion at some institutions.[8–11] Examples of tools that assess oculomotor function are the King-Devick (KD) test (King-Devick Technologies, Inc, Oakbrook Terrace, IL),[12] Vestibular/Ocular Motor Screening (VOMS) tool,[13] and central and peripheral vision reaction times.[14] These modalities evaluate various aspects of oculomotor function, such as smooth pursuit, saccadic eye movements, and convergence. The KD is a timed horizontal-saccadic eye-movement test that requires individuals to quickly read numbers aloud from either spiral-bound paper test cards or an electronic tablet application.[12,15] Performance on the KD and similar tests may be influenced by attention, concentration, reaction time, and processing speed, and therefore, these domains may overlap with performance domains measured using other commonly used assessments, such as those recommended by the NCAA.[5] A number of researchers[16–22] have demonstrated that slower KD time relative to baseline is sensitive in detecting SRC, but its relationship with other concussion tests among collegiate student-athletes is not well understood in either the baseline or postinjury setting.

Our objective was to explore relationships among the KD and commonly used concussion assessments (ie, symptoms, psychological distress, balance, cognitive, and vestibular and oculomotor measures) at baseline in a large sample of collegiate athletes from the NCAA and the Department of Defense Concussion Assessment, Research and Education (CARE) Consortium. The presence or absence of relationships at baseline could help determine the uniqueness of information provided by the KD and potentially provide helpful insight in the postinjury setting.

METHODS

Sample

Baseline assessments (ie, data from uninjured athletes before the start of the competitive season) were obtained from the CARE Consortium. The consortium collected SRC-related measures including baseline and postinjury test results from student-athletes, cadets, and midshipmen at 29 NCAA institutions. Detailed information on the CARE methods has been described.[23]

Participants

All participants provided written informed consent, as approved by the institutional review boards at their respective institutions, the lead study site, and the US Army Human Research Protection Office before their involvement in the CARE Consortium. Student-athletes from the 5 CARE institutions that administered the KD test during the 2014–2015, 2015–2016, and partial 2016–2017 academic years contributed information to this data set. Only baseline results from the student-athlete's first year of study participation were included.

Participating student-athletes also completed a clinical reporting form with self-reported information on demographics and medical history. This included information on age, race, sex, concussion history, academic history, neurodevelopmental and psychological history, and sport participation.

Measures

The following measures were performed at baseline. Their characteristics and the participants' exclusion criteria for this study, where applicable, are described.

King-Devick Test. The KD measures the time to complete a single-digit rapid number-naming task. The KD consists of 1 demonstration card and 3 test cards. The KD was performed using either spiral-bound paper test cards (n = 1567) or an electronic tablet application (n = 691). To perform the KD, each student-athlete read the numbers on each test card or tablet screen aloud from left to right. The combined time (in seconds) to read the numbers on the 3 test cards constituted the total KD time. Higher values (ie, slower time) on the KD reflect worse performance. Varied KD times among participants may result from differences in the ability to perform the saccadic eye movements required for the test, reading ability, concentration or attention to the task, or other factors. During the baseline administration, student-athletes were instructed to state the numbers as fast as possible without making errors. They were required to complete 2 trials of the test on the same modality (spiral-bound paper test cards or the tablet application). If an athlete made an error, he or she performed additional trials on the same modality until an error-free time was achieved. The fastest error-free time was retained as the athlete's baseline. A KD time that was 3 or more standard deviations slower than the mean was considered a statistical outlier and excluded from the analysis (n = 22).

Symptom Checklist. Baseline concussion symptoms were self-reported in graded fashion via the Symptom Inventory of the Sport Concussion Assessment Tool–3rd edition (SCAT3), a 22-item questionnaire that assesses cognitive, somatic, psychological, and sleep-related symptoms typically associated with SRC.[24] The 22 symptoms are assessed on a 7-point Likert scale: 0 indicates the symptom is *not currently present*, 1 to 2 indicates the symptom is currently *mild*, 3 to 4 indicates the symptom is currently *moderate*, and 5 to 6 indicates the symptom is currently *severe*, for a possible symptom severity ranging from 0 to 132. The total number of symptoms (out of 22) and symptom severity (out of 132) were included as predictor variables in the analysis.

Psychological Distress. Psychological distress was assessed with the Brief Symptom Inventory-18 (BSI-18), an 18-item questionnaire that assesses symptoms of anxiety, depression, and somatization during the preceding 7 days.[25] The BSI-18 contains 6 questions for each of the 3 domains assessed on a 5-point Likert scale: 0 indicates that the symptom has *not been present*, 1 indicates that the symptom has been present *a little bit*, 2 indicates that the symptom has been *moderately* present, 3 indicates that the symptom has been present *quite a bit*, and 4 indicates that the symptom has been *extremely* present, for a possible score of 0 to 24 in each domain. Subscores for each domain (anxiety, depression, and somatization) as well as the total score were included as predictor variables in the analysis.

Balance Error Scoring System. The Balance Error Scoring System (BESS) is a measure of postural stability that consists of 3 stances: double-legged stance, nondominant single-legged stance, and tandem stance.[2] Stances are performed with the eyes closed for 20 seconds each on a firm surface and a foam surface, and errors are counted. The maximum error count is 10 for each trial, for a total error range of 0 to 60, with higher scores indicating poorer performance. The number of errors on the firm surface (0–30) and foam surface (0–30) as well as the total errors (0–60) were included as predictor variables in the analysis.

Standardized Assessment of Concussion. The Standardized Assessment of Concussion (SAC) tests cognitive functioning in 4 domains: orientation, immediate memory, concentration, and delayed memory.[26] Scoring for each item is dichotomous: 1 point for a correct answer, 0 points for an incorrect answer or omitted response. Orientation (maximum = 5 points), immediate memory (maximum = 15 points), concentration (maximum = 5 points), and delayed memory (maximum = 5 points) are totaled for a score ranging from 0 to 30; lower scores indicate poorer performance. Domain scores (orientation, immediate memory, concentration, and delayed memory) and the total score were included in the analysis as predictor variables.

Immediate Post-Concussion Assessment and Cognitive Testing. Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT; ImPACT Applications, Inc, San Diego, CA) is a computerized neurocognitive test battery commonly used to evaluate SRC. It comprises 6 subtests,[27] the results of which are used to calculate 4 composite scores: verbal memory, visual memory, visual motor speed, and reaction time. Higher composite scores for verbal memory, visual memory, and visual motor speed indicate better performance, whereas a lower composite score on reaction time indicates better performance. Automated data-integrity checks in the ImPACT program evaluate test performance validity. The CARE protocol indicates that 1 invalid assessment should be repeated (timing of the repeat subtest at the discretion of the institution), but a second invalid assessment is deemed to reflect the athlete's true performance. It is therefore possible that some invalid ImPACT scores were contained in the CARE data set. Because this data set consisted of composite scores only and not individual subtest results, we were unable to calculate validity as typically indicated by ImPACT. Thus, in an effort to minimize the inclusion of invalid ImPACT measures, each composite score was standardized as a *z* score metric, and the data of student-athletes with composite scores 3 or more standard deviations worse than the mean (n = 51) were excluded from the analysis. The other SRC assessments in this study do not have internal validity measures, and as a result, the data were not standardized in this manner.

Vestibular/Ocular Motor Screening. The VOMS was used to measure symptom provocation immediately after the vestibular and oculomotor function tasks.[13] The VOMS assesses (1) smooth pursuits, (2) horizontal saccades, (3) vertical saccades, (4) near-point convergence (NPC), (5) horizontal vestibular-ocular reflex (VOR), (6) vertical VOR, and (7) visual motion sensitivity. Before the assessment, the student-athletes reported their current level of 4 symptoms: headache, dizziness, nausea, and fogginess on a scale of 0 (symptom is *not present*) to 10 (symptom is *severely present*). After the assessment, the student-athletes rated each of the symptoms again. Symptom change scores were calculated by subtracting the preassessment symptom rating from the postassessment symptom rating. Symptom change scores for each of the 7 domains (eg, smooth pursuits, horizontal saccades) were summed for each symptom to create an overall provocation score for each domain. In addition, NPC was assessed via self-report of double vision or observed exophoria and concurrent measurement of the distance (in centimeters) where this occurred from the tip of the participant's nose. Mean NPC values were calculated across 3 trials. The overall symptom provocation score for each domain and mean NPC value were used in the analysis.

Procedures

All sites administered the SCAT3 Symptom Inventory, BSI-18, BESS, SAC, ImPACT, and KD; 2 sites administered the VOMS. Baseline testing was administered by athletic trainers, trained research assistants, and team physicians per the CARE methods.[23] The student-athletes' demographic characteristics are described in Table 1.

Analysis

Assessment of the KD results revealed a normal distribution with minimal, positive skew (skewness = 0.432). A bivariate Spearman rank order correlation grid was used to evaluate the associations between baseline KD time and the nonnormally distributed predictor variables: (1) SCAT3 Symptom Inventory (total number of symptoms and symptom severity), (2) BSI-18 (anxiety, depression, somatization, and total score), (3) BESS (firm surface, foam surface, and total errors), (4) SAC (orientation, immediate memory, concentration, delayed memory, and total scores), (5) ImPACT (visual memory, verbal memory, visual motor speed, and reaction time values), and (6) VOMS (symptom provocation for each subtest—smooth pursuits, horizontal saccades, vertical saccades, NPC, horizontal VOR, vertical VOR, and visual motion sensitivity—as well as mean NPC). Relationships with a small or greater effect size ($\rho > 0.1$) were subsequently included in a multiple regression analysis to evaluate the relative contributions of each individual measure to baseline KD performance. Spearman

Table 1. Demographic Characteristics of Student-Athletes Who Completed Baseline King-Devick Testing

Characteristic	No. (%)	King-Devick Test Mean (95% Confidence Interval)
Sex		
Male	1196 (53.0)	40.1 (39.8, 40.5)
Female	1062 (47.0)	42.1 (41.7, 42.5)
Total	2258 (100)	41.1 (40.8, 41.4)
Race		
White	1556 (68.9)	41.1 (40.8, 41.5)
African American	382 (16.9)	41.3 (40.6, 42.1)
Other	320 (14.2)	40.5 (39.7, 41.2)
Total	2258 (100)	41.1 (40.8, 41.4)
Academic year		
Freshman	877 (38.8)	41.6 (41.2, 42.1)
Sophomore	472 (20.9)	41.2 (40.5, 41.8)
Junior	473 (20.9)	40.6 (40.0, 41.2)
Senior	331 (14.7)	40.4 (39.6, 41.2)
Fifth-year senior	78 (3.5)	40.0 (38.5, 41.4)
Graduate student	20 (0.9)	38.7 (35.8, 41.6)
Missing	7 (0.3)	46.4 (42.4, 50.5)
Total	2258 (100)	41.1 (40.8, 41.4)
Year administered		
2014–2015	771 (34.1)	41.9 (41.4, 42.4)
2015–2016	1429 (63.3)	40.7 (40.3, 41.0)
2016–2017	58 (2.6)	39.6 (37.8, 41.4)
Total	2258 (100)	41.1 (40.8, 41.4)
School		
Humboldt State University	426 (18.9)	40.7 (40.0, 41.4)
University of Georgia[a]	91 (4.0)	44.0 (42.7, 45.4)
University of Florida[a]	576 (25.5)	42.9 (42.3, 43.5)
University of Delaware	591 (26.2)	39.8 (39.3, 40.3)
University of Washington	574 (25.4)	40.4 (39.8, 40.9)
Total	2258 (100)	41.1 (40.8, 41.4)
Learning disorder?		
Yes	106 (4.7)	44.3 (42.8, 45.8)
No	2137 (94.6)	40.9 (40.6, 41.2)
Missing	15 (0.7)	45.9 (42.3, 49.5)
Total	2258 (100)	41.1 (40.8, 41.4)
Attention-deficit/hyperactivity disorder?		
Yes	204 (9.0)	41.7 (40.8, 42.6)
No	2039 (90.3)	41.0 (40.7, 41.3)
Missing	15 (0.7)	45.2 (41.8, 58.5)
Total	2258 (100)	41.1 (40.8, 41.4)
Prior concussions		
0	1590 (70.4)	41.2 (40.8, 41.5)
1	438 (19.4)	40.8 (40.1, 41.5)
2	139 (6.2)	40.6 (39.7, 41.6)
3+	80 (3.5)	40.9 (39.3, 42.5)
Missing	11 (0.5)	43.2 (39.1, 47.4)
Total	2258 (100)	41.1 (40.8, 41.4)

[a] King-Devick testing was administered via electronic tablet application at this institution.

ρ values were used to estimate effect size (0.1 = *small*, 0.3 = *medium*, 0.5 = *large*).[28] For regression analyses, we examined P-P plots and scatterplots of standardized residuals to ensure that assumptions of homoscedasticity were met for each outcome variable. Polynomial terms were also explored for quadratic or cubic relationships. We controlled for sex, history of a learning disorder, history of attention-deficit/hyperactivity disorder, number of previous concussions, primary language other than English, and KD modality (testing using paper test cards versus electronic tablet application) because previous analyses[29,30] have demonstrated significant influences of these factors on KD performance. The Cohen f^2 was calculated by dividing the regression variance explained by 1 minus the variance explained ($R^2/1 - R^2$) and used to estimate effect size (0.02 = *small*, 0.15 = *medium*, 0.35 = *large*).[28]

RESULTS

Student-athletes (N = 2344) completed baseline KD testing during their first year in the study. After the exclusion criteria were applied, the final sample consisted of 2258 participants (age = 20.0 ± 1.5 years; 53.0% male, 47.0% female) from 11 men's and 13 women's sports of varied collision, contact, and noncontact types. Of this final sample, 461 athletes from 5 men's and 8 women's sports completed the VOMS (mean age = 20.3 years; 52.3% male, 63.8% white).

Mean baseline KD time was 41.1 ± 7.0 seconds (range = 24.0–63.1 seconds). Performance statistics for all measures are provided in Table 2. The Spearman bivariate correlation statistics for associations between the predictor variables and baseline KD time are shown in Table 3. Faster KD completion time significantly correlated with better SAC concentration (ρ = –0.216, $P < .001$; small effect size), ImPACT visual motor speed (ρ = –0.267, $P < .001$; small effect size), and ImPACT reaction time (ρ = 0.164, $P < .001$; small effect size). No other correlations with ρ magnitude >0.1 were observed.

Scores for SAC concentration, ImPACT visual motor speed, and ImPACT reaction time were then used as predictors of KD performance in a linear multiple regression analysis while controlling for sex, learning disorder, attention-deficit/hyperactivity disorder, number of previous concussions, primary language other than English, and KD modality (Table 4). Assumptions of noncollinearity were met. The regression model explained 16.8% ($P < .001$, Cohen $f^2 = 0.20$, medium effect size) of the variance in KD baseline times. In the full model, better SAC concentration (β = –.174; 95% CI = –0.197, –0.120; $P < .001$), ImPACT visual motor speed (β = –.205; 95% CI = –0.243, –0.151; $P < .001$), and ImPACT reaction time (β = .056; 95% CI = 0.011, 0.109; $P = .020$) were associated with better KD performance, but the individual effect sizes were small.

Translated clinically, each 1-point increase in SAC concentration was associated with a KD performance that was 1.2 seconds faster. Each 6.2-point increase in ImPACT visual motor speed was associated with a KD performance that was 1.4 seconds faster. Each 0.07-second decrease in ImPACT reaction time was associated with a KD performance that was 0.4 seconds faster.

DISCUSSION

This study revealed several significant yet small-effect associations between baseline KD performance and components of cognition (SAC concentration, ImPACT visual motor speed, and ImPACT reaction time) but no association between KD and reported symptoms, psychological distress, balance, or vestibular/oculomotor provocation screening in collegiate student-athletes. These relationships

Table 2. Baseline Performance on Commonly Used Concussion Measures and the King-Devick Test[a]

Measure	No.	Mean ± SD
Sport Concussion Assessment Tool–3 Symptom Inventory		
Total symptoms	2238	2.5 ± 3.3
Symptom severity	2238	4.3 ± 6.8
Brief Symptom Inventory-18		
Anxiety	2245	0.8 ± 1.7
Depression	2245	0.8 ± 1.8
Somatization	2245	0.9 ± 1.8
Total	2245	2.6 ± 4.2
Balance Error Scoring System		
Firm surface	2195	3.2 ± 3.1
Foam surface	2073	10.7 ± 4.9
Total	2072	13.9 ± 6.7
Standardized Assessment of Concussion		
Orientation	2209	4.9 ± 0.3
Immediate memory	2192	14.5 ± 0.8
Concentration	2209	3.7 ± 1.1
Delayed memory	2176	3.7 ± 1.2
Total	2169	26.8 ± 2.0
Immediate Post-Concussion Assessment and Cognitive Testing[b]		
Verbal memory	1972	86.7 ± 10.2
Visual memory	1972	76.6 ± 12.8
Visual motor speed	1972	40.82 ± 6.20
Reaction time, s	1972	0.59 ± 0.07
Vestibular/Ocular Motor Screening		
Symptom provocation score		
Smooth pursuit	461	0.1 ± 0.6
Horizontal saccades	461	0.2 ± 0.9
Vertical saccades	461	0.2 ± 1.1
Convergence	461	0.3 ± 1.3
Horizontal vestibular-ocular reflex	461	0.7 ± 1.7
Vertical vestibular-ocular reflex	461	0.6 ± 1.9
Visual motion sensitivity	461	0.5 ± 1.8
Mean near-point convergence distance, cm	462	2.9 ± 3.0
King-Devick Test	2258	41.1 ± 76.0

[a] King-Devick Technologies, Inc, Oakbrook Terrace, IL.
[b] ImPACT Applications, Inc, San Diego, CA.

Table 3. Spearman Bivariate Correlation Statistics for Associations Between Commonly Used Concussion Measures and the King-Devick Test[a] at Baseline

Measure	ρ	*P* Value
Sport Concussion Assessment Tool–3 Symptom Inventory		
Total symptoms	−0.004	.861
Symptom severity	−0.002	.935
Brief Symptom Inventory-18		
Anxiety	0.012	.579
Depression	0.033	.116
Somatization	0.032	.125
Total	0.025	.228
Balance Error Scoring System		
Firm surface	0.011	.598
Foam surface	0.021	.350
Total	0.023	.290
Standardized Assessment of Concussion		
Orientation	−0.004	.842
Immediate memory	−0.077	<.001
Concentration	−0.216[a]	<.001
Delayed memory	0.009	.678
Total	−0.152[a]	<.001
Immediate Post-Concussion Assessment and Cognitive Testing[b]		
Verbal memory	−0.051	.023
Visual memory	−0.037	.103
Visual motor speed	−0.267[c]	<.001
Reaction time	0.164[c]	<.001
Vestibular/Ocular Motor Screening		
Symptom provocation score		
Smooth pursuit	−0.016	.725
Horizontal saccades	−0.054	.248
Vertical saccades	−0.008	.864
Convergence	−0.061	.188
Horizontal vestibular-ocular reflex	−0.003	.950
Vertical vestibular-ocular reflex	−0.038	.416
Visual motion sensitivity	−0.050	.283
Mean near-point convergence distance	−0.001	.977

[a] King-Devick Technologies, Inc, Oakbrook Terrace, IL.
[b] ImPACT Applications, Inc, San Diego, CA.
[c] Denotes ρ magnitude ≥0.1.

explained only 16.8% of the variance in baseline KD time, and the individual test relationships had small effect sizes. This suggests the remaining 83.2% of variance in baseline KD times was due to other unmeasured influences not directly assessed by the SRC tests we used. Our findings support the position that KD may measure a domain not addressed by these commonly used SRC assessments at baseline.

Previous researchers who studied fewer participants at different ages also reported that better scores on ImPACT visual motor speed[20] and ImPACT reaction time[31] were associated with faster baseline KD performance. The consistency of our result provides further evidence of overlap between KD and ImPACT speed measures at baseline. This association was not surprising as the KD is a timed horizontal-saccadic eye-movement and recognition task, a function necessary for efficient completion of the ImPACT test modules that load on the visual motor speed (eg, 3-letter distractor "countdown" task and shape ID) and reaction time (eg, symbol-matching response time) composite scores.

Our finding that better SAC concentration scores were associated with better KD performance has not been previously demonstrated. The SAC concentration test requires participants to manipulate strings of numbers and report them in backward order and to name the months of the year in reverse order. Although reporting digits backward is primarily a working-memory task, it requires

Table 4. Linear Regression Statistics for Predictors of King-Devick Test[a] Performance

Predictor Variable	Value		
	β	*t*	*P*
Standardized Assessment of Concussion			
Concentration	−.174	−8.107	<.001
Immediate Post-Concussion Assessment and Cognitive Testing[b]			
Visual motor speed	−.205	−8.311	<.001
Reaction time	.056	2322	.020

[a] King-Devick Technologies, Inc, Oakbrook Terrace, IL.
[b] ImPACT Applications, Inc, San Diego, CA.

attention, which is also required during the KD. However, these results differed from those of Galetta et al,[32] who identified associations between better baseline KD times and better SAC immediate memory and SAC total scores but not SAC concentration in 27 professional ice hockey players. The larger sample size and inclusion of both sexes and collegiate student-athletes from multiple sports in our study may have contributed to the discrepancy.

Performance on the KD was not associated with any of the VOMS measures. Given that the KD is often described as a timed saccadic eye-movement test and that the VOMS includes horizontal and vertical saccades as 2 of its 7 subtests, this lack of a relationship may seem paradoxical. However, this result corroborates findings from Yorke et al,[33] who noted no association between VOMS components and KD performance in nonconcussed adolescents, and suggests the 2 tests may measure different parameters of saccadic eye movement. The KD involves rapid naming of linearly displayed numbers with variable spacing from left to right, and ability is quantified by the time it takes to complete the task. In contrast, the saccades component of the VOMS involves rapid eye movement between 2 fixed points about 3 ft (0.9 m) apart held 3 ft from the eyes for 10 repetitions, with a subsequent rating of symptom provocation without quantifying the time required to complete the task. Moreover, the VOMS saccades component does not involve recognition or naming and focuses only on rapid eye movements and whether such movements trigger symptoms. This difference may explain the lack of association between performances on the KD and VOMS. A relationship might exist between the 2 saccadic assessments if the VOMS quantified the number of completed saccades in a set period of time, as suggested by previous authors,[34] or if symptom provocation was assessed after KD administration.

Total symptoms reported or severity of symptoms on the SCAT3 Symptom Inventory were not significantly associated with KD time at baseline. This was not surprising at baseline, when most participants were asymptomatic. Symptoms such as blurred vision, sensitivity to light, feeling slowed down, difficulty concentrating, and confusion are part of this inventory, and their presence might affect an athlete's KD performance. Future investigators could focus on individual or clusters of symptoms that may be associated with KD performance postinjury.

None of the domain or total BSI-18 scores were related. It is feasible that psychological distress could lead to changes in performance on the KD (eg, depression or anxiety causing poor concentration or attention and a worse KD score), but in our sample, the means for each BSI-18 domain were <1 out of a possible maximum score of 24. This low baseline rate of psychological distress may have limited the ability to detect associations between psychological distress and KD performance. Exploring the relationship of reported psychological distress and KD postinjury, when BSI-18 scores are typically increased, may be useful.

Finally, KD time and postural stability as measured by the BESS were not related. This finding differs from the result of a recent study[35] that showed a relationship between balance as measured by the Sensory Organization Test and cognitive measures such as reaction time and executive function. Although the BESS and KD both require concentration and attention, in a baseline sample of healthy participants, the effects of these factors may be less apparent than in patients postinjury. As the KD requires visual input and the BESS is intentionally performed with the participant's eyes closed, this lack of association at baseline is less surprising.

Our study was limited in several aspects. It involved only NCAA student-athletes, which may lessen its generalizability to individuals of other ages and at other competition levels. Given the large numbers of athletes on different sports teams and at different institutions, testing procedures (eg, test order, training of test administrators, and test setting) may have varied within and between sites, which could have affected the results. Sampling bias could have affected the VOMS findings, as this test was performed at only 2 of the 5 sites. Also, prior exposure of the athletes to each assessment before their first year of participation in the CARE Consortium was unknown, so potential differences in practice effects among the assessments were not taken into account. Finally, we looked only at baseline measures, when variability in performances may be reduced. Whether these relationships, or lack of relationships, are also present postinjury, when performance variability is likely greater, is unknown. Further investigation of this topic was not possible from this early, baseline-only CARE data set, but such postinjury data may be available in the future, and this remains an area for further research.

CONCLUSIONS

Our results suggest that better performance on baseline cognitive measures involving concentration, visual motor speed, and reaction time commonly used in concussion management was weakly associated with faster KD performance, but the effect sizes for these relationships were small. Concussion-like symptoms, psychological distress, postural stability, and vestibular-ocular provocation measures were unrelated to KD performance. Together, these findings indicate limited overlap among these commonly used baseline concussion assessments and KD performance and that the KD may potentially augment current multimodal baseline concussion assessments. However, future authors should explore potential relationships in the postinjury setting.

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