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Comparison and utility of King-Devick and ImPACT® composite scores in adolescent concussion patients

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A B S T R A C T

The King-Devick (KD) oculomotor test has recently been advocated for sideline diagnosis of concussion. Although visual processing and performance are often impaired in concussion patients, the utility of KD as a concussion diagnostic tool is not validated.

Purpose: To examine the diagnostic value of KD, by comparing KD with post-concussion symptom scale (PCSS) and ImPACT® composite scores. We hypothesized that KD would be correlated with visual motor speed/memory (VMS, VIS) and reaction time (RT), because all require cognitive visual processing. We also expected parallel changes in KD and PCSS across recovery.

Methods: Thirty-five concussed individuals (12–19 y; 18 females, 17 males) were evaluated with PCSS, ImPACT® composite and KD scores over four clinical visits (V).

Results: KD times improved with each visit (ΔV1–V2: 7.86 ± 11.82; ΔV2–V3: 9.17 ± 11.07; ΔV3–V4: 5.30 ± 7.87 s) and paralleled improvements in PCSS (ΔV1–V2: 8.97 ± 20.27; ΔV2–V3: 8.69 ± 14.70; ΔV3–V4: 6.31 ± 7.71), RT (ΔV1–V2: 0.05 ± 0.21; ΔV2–V3: 0.09 ± 0.19; ΔV3–V4 0.03 ± 0.07) and VMS (ΔV1–V2: −5.27 ± 6.98; ΔV2–V3: −2.61 ± 6.48; ΔV3–V4: −2.35 ± 5.22). Longer KD times were associated with slower RT ($r = 0.67$; $P < 0.0001$) and lower VMS ($r = -0.70$; $P < 0.0001$), respectively.

Conclusion: Cognitive visual performance testing using KD has utility in concussion evaluation. Validation would further establish KD as an effective ancillary tool in longitudinal concussion management and research.

1. Introduction

Concussion in sport has garnered significant clinical and public concern and media attention, particularly over the last few years. A recent study by the Centers for Disease Control and Prevention indicated that in individuals younger than age nineteen, sports-related concussion accounts for approximately 170,000 emergency department (ED) visits every year. Between 2001 and 2009, the number of ED visits due to concussion in this population increased by 62% [1]. Patients in this demographic are more vulnerable to the effects of head trauma, have an increased risk for long-term complications and tend to have prolonged recovery time when compared with adults [2–4]. The specific symptoms that each patient reports are unique in severity and modulated to some degree by the particular region(s) of the brain affected [5]. Due to this variable nature of concussions, patients need to be treated individually and a unique plan of action should be carried out by their health care provider, based on individual symptoms and functional deficits. Concussion evaluation is often based on self-reported symptom scores, as well as balance and neurocognitive testing. However, newly developed and validated tests continue to provide the physician with additional tools to more specifically profile patient status and guide concussion recovery approaches and accommodation needs.

Diffuse axonal injury (mechanical disruption and axonal swelling, disconnection and reorganization) is considered to be a key underlying cause of the more lasting signs and symptoms (cognitive, emotional, physical and postural, and sleep-related) of concussion[6–8], including visual-motor deficits. Specifically, neuronal injury can prompt impaired visual movements and oculomotor speed in concussed patients [9]. While oculomotor dysfunction in concussed individuals has been well established, research to date has been limited by dissimilar populations sampled and inconsistency in the types of tests used to assess eye movement [10–13]. It is estimated that a certain degree of oculomotor dysfunction is present in 65–90% of patients who have experienced some form of traumatic brain injury [9,14,15]. Visual-motor deficits that are often reported by these patients include difficulty with saccades,

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accommodation, smooth pursuit, fixation, reading, photosensitivity and a number of other related challenges [16,17]. However, objective, validated and field-expedient measurements of visual-motor deficit which potentially affect and are related to cognitive visual performance are not well-recognized and utilized by healthcare providers.

The computerized concussion evaluation system ImPACT® is widely utilized as an aid in concussion diagnosis and recovery. The visual-motor speed (VMS) component of ImPACT® is commonly used for determining visual-motor deficits. Notably, VMS has been shown to be the most reliable of the ImPACT® composite scores [18]. The other composite scores that address visual processing and motor speed are reaction time (RT) and visual memory (VIS). These scores (VMS, RT, and VIS) provide unique information incorporating visual processing, acuity, and oculomotor speed. Deficits in VMS, VIS and RT may reflect axonal damage to oculomotor neurons; however visual processing and performance deficits can have numerous other concussion-related contributing factors.

Clinicians continue to look for convenient tools that can provide accurate and rapid information to assist in evaluating concussions, as well as effective ways to assess and track recovery following the injury. The King-Devick (KD) test is an innovative reading efficiency test that has recently been recommended and utilized for sideline diagnosis of sport concussion [19–22]. This test provides a rapid assessment of cognitive visual processing and performance. Its utility is attractive because of ease of administration and provision of prompt insight to clinical status. While the KD test has been proven to be effective in the acute assessment of concussion [19–22], longitudinal data regarding changes in KD times during the concussion recovery period are currently unavailable. Moreover, research to validate this test against other, more recognized diagnostic tools is lacking. Accordingly, further research is warranted to validate the use of this test to assess concussed patients, particularly in the longitudinal setting.

Even with the development of new and sophisticated technologies and testing methods, symptom scales remain a standard instrument used by clinicians to evaluate concussion severity and status. Symptom scales allow healthcare providers to evaluate and track specific symptoms and deficits unique to each individual patient. Because a concussion remains a clinical diagnosis, reporting of symptoms along with a high index of suspicion remains the cornerstone of concussion management [23]. Symptom scales also provide a subjective measure of concussion recovery and prove useful in making return-to-play and other activity decisions.

This study examined the utility of the KD test by comparing KD longitudinal data with post-concussion symptom scale (PCSS) measures and the four composite scores (verbal memory [VEM], VMS, VIS and RT) from ImPACT® in recently concussed patients. We hypothesized that as patients' self-reported symptoms lessened in severity, there would be a concomitant improvement in KD performance. Furthermore, because of shared characteristics related to cognitive visual processing, we hypothesized that longitudinal KD performance would be correlated with VMS, VIS and RT (VEM was included for completeness, though a relevant association to KD was not anticipated). Significant associations between KD and the ImPACT® composite scores, as well as similar tracking in KD performance and PCSS responses, could help substantiate the clinical utility of the KD test in assessing recovery of concussed individuals. These anticipated findings would support the KD test as an effective and rapid tool in concussion diagnosis and tracking longitudinal recovery in patients. Accordingly, the KD test could also assist healthcare providers in making more objective return-to-play and return-to-school decisions for student-athletes.

2. Methods

Thirty-five concussed individuals (Table 1) were recruited through a local sports medicine clinic (Sanford Orthopedics & Sports Medicine Clinic; Sioux Falls, SD). Inclusion criteria were: 1) 12–24 y, 2) closed head injury with diagnosis of concussion by a board certified sports medicine physician, and 3) a minimum of four physician office visits for clinical care of the diagnosed concussion. We determined that four discrete time points were necessary to adequately assess changes in symptom resolve and other measured outcomes in a longitudinal manner. The various settings for incurring the concussions and number of days following the injuries until the first visits are also indicated in Table 1. Informed written consent was obtained from each participant, as well as from a parent when a potential subject was younger than eighteen years old. The Sanford Research Institutional Review Board reviewed and approved this study.

2.1. Testing protocol

During each of four clinical visits (typically 2.5 to 4 weeks between visits), each subject participated in a number of post-concussion assessments, including PCSS evaluation, KD test and ImPACT®. These evaluations and tests took place at the Sanford Orthopedics & Sports Medicine Clinic in Sioux Falls, SD and were administered by experienced certified athletic trainers in the same order each time. Some subjects required additional clinical visits, but only data from the first four visits were included in this study.

PCSS values were recorded through a standard 22-question form in which the patients graded their symptoms (categorized as physical, cognitive, emotional and sleep) on a 7-point Likert scale of 0–6, with "0" meaning the patient was not experiencing the symptom at all and "6" meaning the symptom was very severe. Subjects were asked to rate only the symptoms that they were experiencing at the time of evaluation.

After the PCSS evaluation, cognitive visual performance was assessed with the KD test, Version 2 (available at http://www.kingdevicktest.com. Accessed July 30, 2013). The KD test requires subjects to rapidly read single-digit numbers from a series of three cards. The numbers on each card are uniquely arranged and spaced, with a progressive increase in difficulty with each successive card. Subjects were given standard instructions and asked to read the numbers from left-to-right, top-to-bottom, as rapidly as possible without making an error. Cards were held by each patient at a self-chosen comfortable distance for reading. The time to complete each card was measured with a

Table 1
Demographic information of study sample.

	Number and percentage of all participants (n = 35)
Sex	
Male	17 (48.6%)
Female	18 (51.4%)
Sport	
Basketball	5 (14.3%)
Cheer	3 (8.6%)
Football	9 (25.7%)
Gymnastics	1 (2.9%)
Soccer	3 (8.6%)
Wrestling	6 (17.1%)
OtherActivity	8 (22.9%)
Days after concussion for first visit	
1–5	2 (5.7%)
6–10	14 (40.0%)
11–21	7 (20.0%)
22–30	3 (8.6%)
>30	9 (25.7%)
Age	
12	2 (5.7%)
13	1 (2.9%)
14	6 (17.1%)
15	10 (28.6%)
16	6 (17.1%)
17	5 (14.3%)
18	4 (11.4%)
19	1 (2.9%)

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stopwatch to the nearest hundredth of a second, and the number of errors was noted and recorded. Subjects were given up to three attempts to complete each card. This allowed us to obtain the most accurate representation of the participants' cognitive ability in the case the participant stumbled or lost their place on the card. Each test was performed without an error to ensure the participants were not reading through the cards as fast as they could without regard for the number of errors they commit in order to give a falsely faster score. The fastest time without an error was recorded for each card, and the best times were summed for a total time.

Following the KD test, the online version of ImPACT® was administered. Each individual went through the series of six unique testing modules that measure attention span and time, working memory, response variability, non-verbal problem solving and reaction time. A comprehensive report was automatically generated upon completion, where the VEM, VIS, VMS and RT composite scores could then be utilized in separate comparisons with the KD results.

2.2. Statistical methods

Means and standard deviations for each variable at each visit were computed after inspection of data for unusual values. Correlations between variables, corrected for subject-specific intercepts, were computed by the method of Bland and Altman [24] (this removes subject intercept, but ensures that parallel lines are fitted between subjects).

To examine the change in symptoms, ImPACT® composite scores and KD performance over all visits, mixed-model repeated measures were used. For these analyses, unstructured covariance matrices were used. Visit (V) 1 was compared against the remaining three visits, V2 against the remaining two and V3 against V4, in order to detect a "break" in the slope of means. Statistical significance for all analyses was set at $P < 0.05$.

3. Results

Of the 204 concussion patients seen in our clinic during the period of this study who met the age and diagnosis inclusion criteria, we included only those patients (35) who required four or more clinical visits for us to observe symptom resolve. The number of days after the concussion before the first visit varied greatly with about 25% of our study group being first seen more than thirty days post-concussion (Table 1). As a whole, however, the group demonstrated consistent symptom resolve and improvement in the other outcome variables across the four visits. Fourteen out of the thirty-five (40%) participants in this study had experienced an additional prior concussion. However, there was no statistical relationship between any outcome measure (KD time, PCSS and ImPACT®) and number of previous concussions.

Age at initial visit (V) was 16.1 ± 1.7 y. Additional demographic information is presented in Table 1. Fig. 1 presents means for the measured outcome variables of interest. KD times and PCSS scores progressively decreased over the course of four visits (KD ΔV1–V2: 7.86 ± 11.82; ΔV2–V3: 9.17 ± 11.07; ΔV3–V4: 5.30 ± 7.87 s; PCSS ΔV1–V2: 8.97 ± 20.27; ΔV2–V3: 8.69 ± 14.70; ΔV3–V4: 6.31 ± 7.71). Three of the ImPACT® composite scores increased over the four visits (VEM ΔV1–V2: -8.68 ± 12.60; ΔV2–V3: -6.61 ± 13.31; ΔV3–V4: -1.78 ± 11.26; VIS ΔV1–V2: -5.01 ± 14.00; ΔV2–V3: -4.73 ± 17.52; ΔV3–V4: -3.68 ± 11.26; VMS ΔV1–V2: -5.27 ± 6.98; ΔV2–V3: -2.61 ± 6.48; ΔV3–V4: -2.35 ± 5.22), while RT progressively decreased (ΔV1–V2: 0.05 ± 0.21; ΔV2–V3: 0.09 ± 0.19; ΔV3–V4 0.03 ± 0.07). These findings were consistent with the notion that the participants were progressively recovering from their brain injuries, across the period of the study.

All correlations between ImPACT® composite scores (as well as symptoms) and KD results indicated parallel improvement — that is, as ImPACT® composite scores improved and symptoms resolved, we observed faster KD times (Fig. 2). All correlations were significant, with *P* values less than 0.0001 in all cases (*P* values not shown).

4. Discussion

The results of this current study support our hypothesis that deficits and resolution in KD performance times are associated with deficits and improvements in ImPACT® (specifically, VMS, VIS, VEM and RT; Fig. 2). This underscores the similar manner in which KD and three (VMS, VIS and RT) of these composite scores assess and reveal concussion-related variations in cognitive visual processing. Interestingly, VEM was closely associated with KD. While this was not an expected outcome specific to our hypothesis based on shared qualities of visual performance assessment among KD and the other three composite scores, this relationship warrants further investigation. The weaker relationship between KD performance and PCSS is likely somewhat explained by the specificity of KD to just visual performance (unlike the more broad PCSS assessment). The correlation between VIS composite and KD performance likewise demonstrates the extent to which deficits and changes in rapid visual scanning and cognitive processing of fixed images (or numbers/letters) are similarly revealed by each of these methods of assessment.

While ImPACT® composite scores can delineate more specific aspects of visual performance, KD performance appears to provide insight to these same deficits and changes collectively. This is demonstrated in the similar step-wise pattern of resolve seen across the four clinical visits. Recognized current concussion management guidelines suggest serial monitoring of concussion recovery through both objective and subjective testing measures [25,26]. Accordingly, neuropsychological and balance testing and PCSS evaluations are prevalent components of concussion management strategies by clinicians. As others have shown [19–22], our findings also support the utility of the KD test in acute concussion diagnosis. Notably, KD also appears effective in longitudinal observation and tracking certain aspects of concussion recovery in patients to assist healthcare providers in making return-to-play and return-to-school decisions.

The PCSS is an updated version of the earlier post-concussion scale (PCS) [27]. According to Lovell et al, "The PCS was developed to provide a formal method of documenting post-concussion symptoms, as perceived and reported by the athlete. In particular, the goal in developing this scale was to more objectively document the often highly subjective symptoms reported by athletes following concussion by assigning numeric values to each symptom"[27]. Previous research has shown an association between PCSS and other neurocognitive tests including ImPACT®, CogSport, Test of Attentional Performance (TAP), and CANTAB®, as well as fMRI [28–30]. Using PCSS and neurocognitive testing together has been shown to increase concussion identification by nearly 30% compared to PCSS alone [30,31]. Accordingly, ImPACT® contains its own PCSS component, in addition to the neurocognitive evaluation.

An oft-mentioned limitation in relying on PCSS is the inherent subjectivity of the questionnaire and the ability of the patient to mislead the provider, in order to more promptly return to play and other activities [32]. Notably, however, PCSS scores in our subjects were higher on their initial visit (37.4 ± 21.9) compared to those same normative data for student-athletes who were evaluated within five days of sustaining a sports-related concussion (24.0 ± 20.0) [27]. A wide range of variability in PCSS has been shown among concussed individuals. One study demonstrated PCSS scores ranging from 0 to 92 with a standard deviation of 20 [27]. Given this variability and apparent subjectivity of PCSS, there may be an advantage and clinical value in using more objective testing such as KD when self-reported symptoms may be in question.

The KD test has been traditionally used as a tool to evaluate reading efficiency in children that may be compromised by dyslexia or impaired saccadic eye movements [33]. More recently, it has been promoted as a practical sideline concussion tool for its ease of administration and the rapid manner in which it can be performed (usually less than 2 min).

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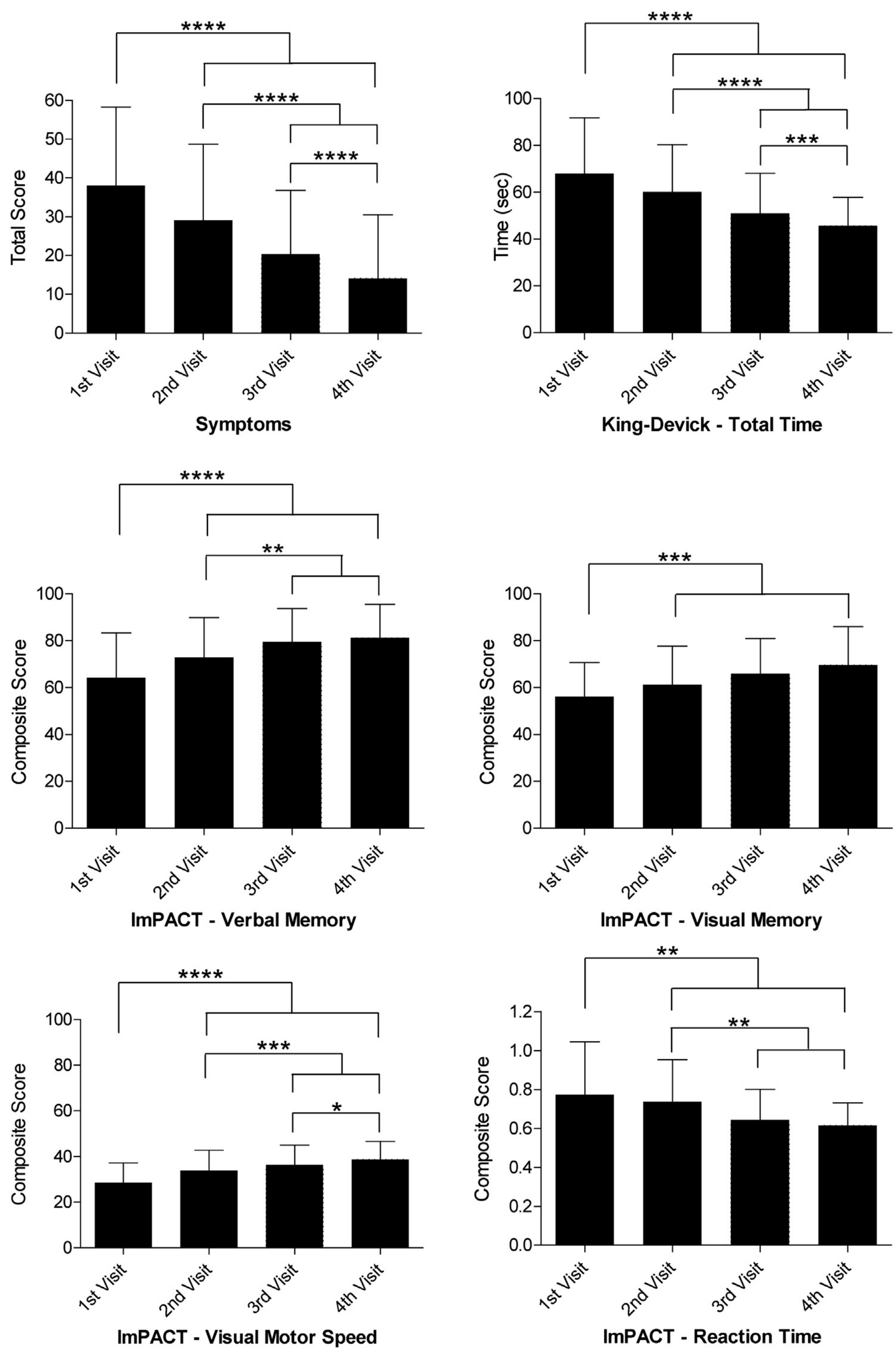

Fig. 1. Temporal changes in PCSS, ImPACT® composite scores, and KD performance over four clinical visits. Visit (V) 1 was compared against the remaining three visits, V2 against the remaining two and V3 against V4, in order to detect a "break" in the slope of means. *P* values are as follows: *<0.05; **<0.01; ***<0.001; ****<0.0001.

The desirability of a rapid, easy to administer test extends beyond the sideline. Many new diagnostic tests for concussion evaluation require expensive, sophisticated equipment (balance platforms, NeuroCom, fMRI, etc.) that are not readily available to most athletic trainers and physicians. The KD test is relatively low-cost and requires a minimal level of expertise to administer on the sideline or in the locker room.

Recent research has shown longer (worse) times on the KD test in concussed collegiate athletes [19] and amateur rugby players in the acute setting [21]. KD has also shown promising results as a ringside tool in boxing and mixed martial arts (MMA), as those who experienced head trauma during a match had worse KD times than those who did not [20]. The concurrent progressive improvement in symptoms and KD performance we observed demonstrates the utility of this test to monitor symptom resolution. Specifically, our findings indicate that the KD test is effective in assessing recovery of oculomotor speed and visual processing, which are among the most frequently reported symptoms in concussed patients.

Current recommendations for post-concussion management include cognitive and physical rest and treating symptoms as needed [26]. Cognitive rest should encompass abstaining from activities that recreate symptoms as well as those that demand measurable concentration and attention, including schoolwork, reading, and video games

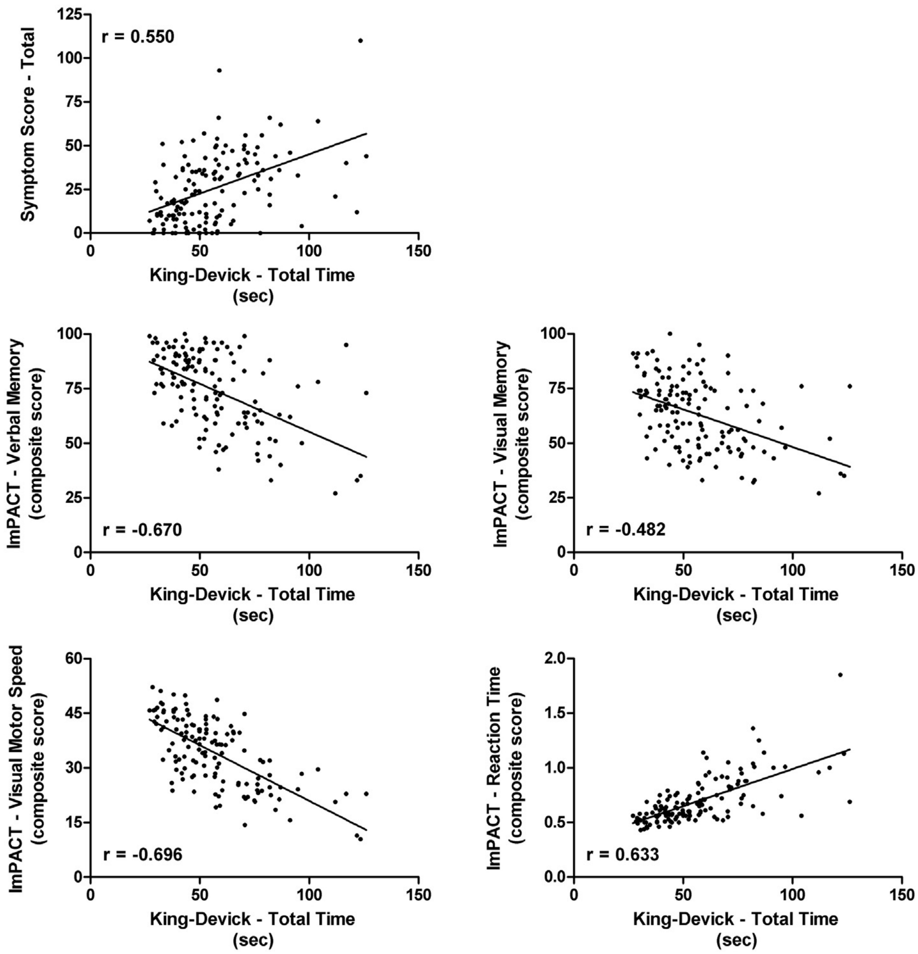

Fig. 2. Correlations between King-Devick total time and ImPACT® composite test scores. r values are shown. All correlations were significant, with *P* values less than 0.0001 in all cases (*P* values not shown).

[25,26,34]. The KD test appears sensitive at revealing residual visual performance-related effects of concussion and progressive recovery over time. Tracking KD performance may be especially useful for evaluating adequate cognitive rest and guiding subsequent return-to-play decisions.

5. Limitations

Notably, KD times are affected by the reading abilities of the participant [35]. Furthermore, a small but significant learning effect has been observed when using the KD test [19,20,22,36]. While this is not uncommon in timed tests [20], the magnitude of this effect over four clinical visits is unknown. However, the residual effect of concussion is likely to override any learning response. Accordingly, it is anticipated that distinct post-concussive improvements would still be present and be the predominant influence of the response, even with a learning effect. This is evidenced by the parallel between total times of the KD test and PCSS values, in which both measures progressively tracked downward (improved) in a very similar, step-wise pattern.

With the specific inclusion criteria of this study, we were only able to evaluate 35 concussed youth. However, we anticipate that a larger sample size would yield similar results. Furthermore, baseline KD times were unavailable for our study population and might have helped to further assess the degree of concussion recovery. While baseline data were not available for our subjects, concurrent improvements in KD performance and PCSS were indicators of concussion resolution over time. Many participants in this study presented to the sports medicine clinic after evaluation and treatment by a primary care physician was ineffective. Thus, these participants were not seen until many days to weeks after their initial head injury.

6. Summary

In conclusion, improvements in ImPACT® and KD performance paralleled each other during the period of concussion recovery. Specific to our hypothesis, VMS, VIS and RT ImPACT® composite scores were shown to be significantly correlated to the KD test times. This underscores the degree to which both tests assess and reveal concussion-related variations in visual processing and oculomotor speed. Notably, the KD test appears effective in objectively monitoring concussion recovery and symptom resolve over several months. These findings support using KD testing in an acute setting and as part of a multidimensional approach to assessing concussion status during a potential long-term recovery period. The unique appeal of the KD test lies in the rapid, easy manner in which it is administered while still providing reliable, objective results. This can help healthcare providers make the most informed clinical decisions regarding return to activity and academic norm.

7. Future research

Larger-scale research involving more subjects over a longer period of time will provide increased validity for using the KD test in myriad clinical and research settings. Evaluating the presence and persistence of a learning effect with the KD test in individuals who have not experienced head trauma would also be helpful in clarifying this potential

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limitation. Normative data for the KD test are available for 6–14 year olds [33]. However, normative KD performance for older teenagers and adults would be beneficial when baseline scores are not available for this population of concussed individuals.

Conflict of interest

The undersigned authors of the enclosed article declare that they do not have potential conflicts of interest regarding this article submitted to the Journal of the Neurological Sciences.

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