RESEARCH ARTICLE

ACTA Vol. 13, No. 3, 2015, 229-236
NEUROPSYCHOLOGICA

Received: 12.02.2015
Accepted: 11.09.2015

A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection

DOI:10.5604/17307503.1172473

THE KING-DEVICK TEST: AN INDICATOR OF LONGER-TERM COGNITIVE EFFECTS POST-CONCUSSION

John P.K. Bernstein[1,2] (A,B,C,D,E,F), Laura S. Mitchell[3](C,D,E), Jeffrey J. Bazarian[3](A,B,E), John T. Langfitt[4](A,C,D,E)
[1] Department of Psychology, University of Rochester, Rochester, USA
[2] Department of Psychology, Louisiana State University, Baton Rouge, USA
[3] Department of Emergency Medicine, University of Rochester School of Medicine, Rochester, USA
[4] Department of Neurology, University of Rochester School of Medicine, Rochester, USA

SUMMARY

Background: The King-Devick test (K-D) was introduced in 2011 as a quick, easy and cost-effective way to screen for a concussion. Relying on differences in visual scanning between a baseline and post-injury examination to discern a concussion, the test has been found to be sensitive to concussions immediately (within minutes) following injury. The aim of this paper was to determine whether the K-D is sensitive to residual effects of a concussion.

Material/ Methods: Performance on the K-D was compared in a sample of 13 subjects tested 1-60 days after a concussion and 17 matched non-concussed controls. We also compared subjects' performances on standard neuropsychological measures of convergent validity (attention, working memory and processing speed) and discriminant validity (IQ and motor speed).

Results: Consistent with hypotheses, concussed subjects performed worse on the K-D than non-concussed subjects. K-D performance was correlated with tests that measured attention and processing speed, but was unrelated to estimated IQ. There was a trend for subjects with a prior history of concussion to perform worse on the K-D than subjects for whom this was their first concussion.

Conclusions: These results provide initial support for convergent and criterion validity of the K-D as a measure of attention and processing speed that is sensitive to persisting effects of concussion.

Key words: head injury; attention, speed processing

INTRODUCTION

Between 1.6 and 3.8 million athletes suffer sports-related concussions every year (Langlois, Rutland-Brown & Wald, 2006). Symptoms frequently associated with a concussion include headache, dizziness, amnesia and confusion in the minutes following injury (Lovell et al., 2007). In addition to these immediate effects, concussions appear to result in post-injury neuropsychological insults, including reduced attention, worsened executive functioning and visuospatial skills (Collins et al., 1999).

The King-Devick test (K-D) has been proposed as a reliable, simple and inexpensive assessment of cognitive functioning after sports-related injury (Galetta et al., 2011a; Galetta et al., 2011b; King, Clark & Gissane, 2012). The K-D measures the total time to scan and read aloud large arrays of numbers printed on three cards which put progressive demands on eye-tracking. Eye-tracking has been found to be a reliable indicator of neuropsychological deficits in concussed individuals (Heitger et al., 2004).

Previous studies of the K-D have centered on the test's capacity to assess concussions in the immediate aftermath of an injury. Galetta and colleagues (2011a) found that mixed martial arts fighters and boxers who suffered head trauma during a match showed longer reading times (compared to pre-match times) on the K-D in the minutes post-injury than did those who did not suffer head trauma. Performance on the K-D correlated with performance on the Military Acute Concussion Evaluation (MACE), a more established test of post-concussion cognition (French et al., 2008). In a follow-up longitudinal study, Galetta and colleagues (2011b) confirmed their previous findings in a sample of football, soccer and basketball players. Players who suffered in-game head trauma performed more slowly on an immediately post-injury sideline test relative to their pre-season baseline than did those who did not suffer head trauma. As in the prior study, K-D and MACE scores correlated both at baseline and post-injury. Finally, in a more recent study, King, Clark and Gissane (2012) compared the K-D performance in New Zealand rugby players in to scores on the Post-Concussion Symptoms Scale (PCSS) of the Sport Concussion Assessment Tool. During competition, players who reported signs of concussion or who the team medic deemed to possibly have a concussion were administered a K-D and a PCSS within 30 minutes of injury. Both the test-retest differences of the K-D and PCSS assessment found evidence of a concussion in all cases.

All of these studies have examined the sensitivity and validity of the K-D in the minutes following injury, yet post-concussive symptoms have been shown to persist for days and even weeks following injury (Lovell et al., 2007). No prior studies have tested whether the K-D is sensitive to the longer-term cognitive effects of concussion. If it were, this would contribute to the overall clinical and practical value of the test as a concussion assessment tool.

The current study sought to determine whether the K-D is sensitive to the persisting cognitive effects of a concussion in the days and weeks following injury and whether performance on the K-D is associated with other cognitive abilities that are typically affected by concussion and is less associated with cognitive abilities that are less affected.

METHODS

Subjects

Thirteen recently concussed subjects and seventeen control subjects without a history of concussion were recruited for this study. Concussed subjects were recruited from a concussion clinic in the Upstate New York area between 24 hours and 60 days following a sports-related concussion. Subjects ranged in age between 18-24 years, with an average age of 20.5 years. Age and gender-matched control subjects were recruited from the psychology undergraduate pool at the University of Rochester and were offered extra credit toward their psychology classes as the primary incentive for their participation. All study procedures were carried out with the approval of the Research Subjects' Review Board at the University of Rochester. Demographic information was obtained from all subjects prior to data collection. Elapsed time since most recent concussion and concussion history was also recorded for concussed subjects.

Subjects who were non-native English speakers were excluded due to test materials being available solely in English. Subjects who had undergone neuropsychological assessment within the past six months, were currently taking stimulant medication, or reported a history of learning disability, autism, mental retardation or ADHD were excluded in order to ensure adequate power by reducing variability. Control subjects who reported suffering a head injury within the past two months were also excluded.

Measures

King-Devick (K-D) Test: The K-D is a neuropsychological test that measures the speed at which a subject performs eye saccades through the rapid reading of a string of numbers (Galetta et al., 2011a; Galetta et al., 2011b). Subjects read aloud a random sequence of single digit numbers presented on a card from left to right. Subjects are instructed to read the numbers as quickly as possible without making any errors. Test administrators demonstrate the task on a sample card, after which subjects complete the task for three total cards that increase in difficulty. Subjects are timed while reading each card and the total sum of the three test card times constitutes the test score. Number of errors made during card reading is also recorded. The K-D has demonstrated high levels of validity and test-retest reliability (0.97) (Galetta et al., 2011b).

Additional Measures

The Hopkins Adult Reading Test (HART) (Schretlen et al., 2009) was included to determine whether any differences in K-D performance might be explained by different levels of general intellectual ability of academic experience within this relatively homogenous sample. The HART is a test of oral reading of irregularly spelled words that provides an estimate of pre-morbid IQ when combined with demographic data. Standardized and well-validated neuropsychological measures of visual scanning and attention, auditory working memory, speed of information processing and motor speed were included to assess residual effects of concussion independent of K-D results and to assess convergent validity of the K-D. Measures included the *Trail Making Test* (TMT) (Tombaugh, 2003). *Brief Test of Attention* (BTA*)* (Schretlen, Bobholz & Brandt, 1996), and the *Finger Tapping Test* (FTT) (Morrison, Gregory & Paul, 1979).

Statistical Analyses

Independent samples t-tests were used to assess group differences between concussed and non-concussed subjects and between those concussed subjects with and without a history of prior concussion. The relationship between K-D results and other cognitive test results was determined using Pearson's correlation coefficient.

RESULTS

Sample Characteristics

There were no differences between concussed and non-concussed subjects in gender, age, or level of education (see Table 1).

The non-concussed group was more racially heterogeneous, probably reflecting the greater racial heterogeneity of the university undergraduate population compared to the mostly white populations served by the concussion clinic.

Presence of Concussion

Cognitive Test Performance is presented in Table 2. It was found that concussed subjects took longer to complete the K-D than did non-concussed subjects ($p<.001$). They also were able to recall fewer numbers and letters on the BTA (both $p<.05$). The groups did not differ on the other measures (TMT-A & B, HART or FTT with either hand).

Table 1. Demographics

	Concussed (n=13)	Non-Concussed (n=17)
Female, n (%)	6 (46)	7 (41)
Race, n (%)		
Caucasian	12 (92)	11 (65)
African American	--	2 (12)
Asian	1 (8)	4 (24)
Age, mean years ± SD	20.5 ± 1.6	19.8 ± 1.2
Education, mean years ± SD	14.4 ± 1.2	14.4 ± 1.1
History of Prior Concussion, n (%)	7 (54)	--

Table 2. Cognitive Test Performance

	Concussed	Non-Concussed
Mean K-D Time (seconds)**	0:56.2 ± 0:12.8	0:46.4 ± 0:06.7
Prior Concussion (seconds)	1:00.9 ± 0:13.7	--
No Prior Concussion (seconds)	0:50.7 ± 0:10.2	--
Mean K-D Errors	.23 ± .44	.29 ± .69
Mean BTA Numbers Score*	8.0 ± 1.9	8.4 ± 1.4
Mean BTA Letters Score*	7.5 ± 1.9	8.6 ± 1.2
Mean Trails A Time (seconds)	33.6 ± 08.3	27.4 ± 10.4
Mean Trails B Time (seconds)	61.6 ± 10.1	52.6 ± 15.2
Mean HART Score	22.3 ± 5.4	23.6 ± 4.4
Mean Finger Tapping Score (Dominant)	48.7 ± 11.6	48.6 ± 9.3
Mean Finger Tapping Score (Non-Dominant)	44.4 ± 9.3	44.7 ± 7.9

* p<.05, ** p< .01

Prior History of Concussion

Concussed subjects with a prior history of concussion took approximately 10 seconds longer to complete the K-D than concussed subjects without a prior history of concussion, a difference that did not reach statistical significance (p=.16). Concussed subjects without a prior history of concussion performed similarly to non-concussed subjects. Concussed subjects with a history of concussion also performed worse on the FTT (non-dominant) than concussed subjects without a history of concussion (p<.05).

Convergent Validity: K-D time was associated with BTA Numbers (r= -0.40, p<.05), BTA Letters (r = -0.55, p < .01), TMT-A time (r= 0.62, p < .01), TMT-B time (r = 0.48, p<.05) and FTT (Dominant Hand) (r= -.48). K-D time was not associated with performance on the HART (r = -0.09) or FTT non-dominant hand performance (r =.-36).

DISCUSSION

Results of this study suggest that the K-D is sensitive to the persisting effects of a concussion in the days and weeks following injury. Concussed subjects took significantly longer to complete the K-D than did non-concussed subjects. Groups also differed on BTA performance, indicating that the observed difference in K-D performance is unlikely to be an artifact of the K-D's task demands. This was true despite similar reading levels and years of education between groups, implying that differences in performance on the K-D was unlikely to reflect differences in broad baseline cognitive abilities. Although groups did not differ on other standard neuropsychological tests, the performance of the group as a whole on most of these tests was associated with K-D times. Together, these findings provide evidence for convergent and criterion validity of the K-D as a measure of attention and processing speed that is sensitive to persisting effects of concussion.

The current results are consistent with the findings of Galetta and colleagues (2011a, 2011b) that recently concussed subjects perform slower relative to their baseline on the K-D than do non-concussed subjects. Despite a much smaller sample size than that in Galetta et al. (2011b) (N = 219), our study was still able to confirm the association between concussion and performance on the K-D. Moreover, the current study found a significant difference in performance between groups despite assessing individuals whose injuries had occurred in the non-immediate past, suggesting that the K-D is sensitive to differences in cognitive functioning in the days and weeks following injury.

We also showed that performance on the K-D is associated with measures of other abilities typically affected by concussion and less so with measures that are typically unaffected. These findings are consistent with previous works suggesting the validity of the K-D (Galetta et al., 2011a; Galetta et al., 2011b; King, Clark & Gissane, 2012). However, we did find a relationship between K-D Time and FTT. This may reflect an association between attention span and performance on the FTT (Friedman, Polson & Dafoe, 1988). Thus, future studies studying the discriminant validity of the K-D might compare performance to neuropsychological measures that have less of an attentional component.

Finally, our study found a non-significant trend for subjects with a prior history of concussion to take longer to complete the K-D than subjects for whom this was their first concussion. A growing literature suggests that individuals with a history of concussion perform worse on neuropsychological tests of attention and visuospatial skills than those who have suffered only one concussion (Guskiewicz et al., 2003). Our study further found that concussed subjects without a prior concussion and non-concussed subjects performed similarly on the K-D. Such findings suggest that differences in K-D performance between the concussed and non-concussed groups are driven by prior concussion history.

Limitations and Future Research

The relatively small sample size limited our ability to find significant differences in K-D performance between concussed subjects with and without a prior history of concussion. Further, as Chantsoulis and coworkers (2015) have noted, cognitive symptoms that develop after brain injury vary from one individual to another, and the severity of these symptoms may change over the course of recovery and rehabilitation. Larger studies recruiting a greater number of concussed participants, including those with and without prior history of concussion, would better be able to draw conclusions in these areas.

The concussed and non-concussed groups were matched for gender and age, but we were unable to control for differences in racial composition between the groups. Specifically, there was greater racial heterogeneity within the non-concussed group than within the concussed group. This difference between groups is the result of the comparatively more racially diverse University population relative to the predominantly white population served by the clinic.

We cannot rule out the possible role that diagnosis threat played in this study (Chantsoulis et al 2015). Concussed subjects were made aware at consent that they were being included in the study on the basis of their concussion. As Suhr and Gunstad (2010) have demonstrated, subjects who are reminded about their history of prior head injury tend to perform more poorly on neuropsychological tests and report putting less effort into completion of such tests than subjects with a similar head injury history that are not reminded of their medical history. Thus, differences in performance on the K-D between concussed and non-concussed subjects may to some degree reflect the tendency for concussed subjects to see themselves at a disadvantage in relation to the non-concussed group. However, given the mild dose effect found in relation to prior history of concussion (albeit non-significant), there appears to be some relationship between concussion and K-D performance that diagnosis threat fails to explain.

Furthermore, given that the K-D was intended to serve as a test-retest measure, the lack of baseline data in this study may limit sensitivity. It is possible that the concussed group had more limited cognitive abilities than the non-concussed group even prior to their head injuries, and thus differences in performance may simply be the result of these non-injury related disparities. That said, this study found little difference between the groups in vocabulary and education levels, suggesting that they likely had similar baseline cognitive capacities.

Despite these limitations, the current results show that the K-D was capable of detecting differences in performance between concussed and non-concussed subjects, and performance on the K-D was both related to other tests that are sensitive to the persisting effects of a concussion and relatively unrelated to tests that are not sensitive to these effects. These results were found despite a small sample size and the injury occurring as much as 60 days prior to assessment. Simple, cost-effective tests that are sensitive to these effects in the longer-term aftermath following injury might contribute to early identification of vulnerable individuals and to our understanding of the specific skills and abilities that are most impacted. Future research utilizing a larger sample size provide further information about the validity of the K-D, and comparison of performance on the K-D to that of a greater variety of neuropsychological assessments might further our understanding as to the specific constructs that the K-D is capable of assessing.

ACKNOWLEDGEMENTS

Sincere gratitude is extended to Noreen Connolly for her assistance in study management. The findings from this paper were previously presented at the 2014 National Conference for Undergraduate Research at the University of Kentucky in Lexington, KY.

REFERENCES

Chantsoulis, M., Mirski, A., Rasmus, A., Kropotov, J.D., & Pachalska, M. (2015).
Neuropsychological rehabilitation for traumatic brain injury patients. *Annals of Agricultural and Environmental Medicine*, 22 (2), 373-384.

Ciuffreda K.J., et al. (2008) Vision therapy for oculomotor dysfunctions in acquired brain injury: A retrospective analysis. *Optometry*, 79, 18-22.

Collins, M.W., Grindel, S.H., Lovell, M.R., Dede, D.E., Moser, D.J., Phalin, B.R., Nogle, S., Wasik, M., Cordry, D., Klotz-Daugherty, M., Sears, S.F., Nicolette, G., Indelicato, P., & McKeag, D.B.

(1999). Relationship between concussion and neuropsychological performance in college football players. *The Journal of the American Medical Association, 282(10)*, 964-970.

French, L., McCrea, M., & Baggett, M. (2008). The Military Acute Concussion Evaluation (MACE). *The Journal of Special Operations Medicine*, 8 (1), 68-77.

Friedman, A., Polson, M.C., & Dafoe, C.G. (1988). Dividing attention between the hands and the head: performance trade-offs between rapid finger tapping and verbal memory. *Journal of Experimental Psychology: Human Perception and Performance*, *14* (1), 60-68

Chantsoulis M, Mirski A, Rasmus A, Kropotov JuD, Pachalska M. Neuropsychological rehabilitation for traumatic brain injury patients. Ann Agric Environ Med. 2015; 22(2): 373–384.

Galetta, K.M., Barrett, J., Allen, M., Madda, F., Delicata, D., Tennant, A.T., Branas, C.C., Maguire, M.G., Messner, L.V., Devick, S., Galetta, S. L., & Balcer, L.J. (2011a). The King-Devick test as a determinant of head trauma and concussion in boxers and MMA fighters. *Neurology*, *76*, 1456-1462.

Galetta, K.M., Brandes, L.E., Maki K., Dziemianowicz, M.S., Laudano, E., Allen, M., Lawler, K., Sennett, B., Wiebe, D., Devick, S., Messner, L.V., Galetta, S.L, Balcer, L.J. (2011b). The King-Devick test and sports-related concussion: study of a rapid visual screening tool in a collegiate cohort. *Journal of the Neurological Sciences, 309,* 34-39. doi: 10.1016/j.jns.2011.07.039

Guskiewicz, K.M., McCrea, M., Marshall, S.W., Cantu, R.C., Randolph, C., Barr, W., Onate J.A., & Kelly, J.P. (2003). Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA concussion study. *The Journal of the American Medical Association*, *290* (19). 2549-2555.

Heitger, M., Anderson, T., Jones, R., Dalrymple-Alford, J., Frampton, C. & Ardagh, M. (2004). Eye movement and visuomotor arm movement deficits following mild closed head injury. *Brain: A Journal of Neurology, 127 (3)*, 575-590.

King, D., Clark, T., & Gissane, C. (2012). Use of a rapid visual screening tool for the assessment of concussion in amateur rugby league: A pilot study. *Journal of the Neurological Sciences*, *320*, 16-21.

Langlois, J., Rutland-Brown, W., & Wald, M. The epidemiology and impact of traumatic brain injury: a brief overview. *Journal of Head Trauma Rehabilitation*, *21* (*5)*, 375-378.

Lovell, M.R., Pardini, J.E., Welling, J., Collins, M.W., Bakal, J., Lazar, N., Roush, R., Eddy, W.F., Becker, J.T. (2007). Functional brain abnormalities are related to clinical recovery and time to return-to-play athletes. *Neurosurgery, 61*, 352-360.

Morrison M.W., Gregory R.J. & Paul J.J. (1979). Reliability of the finger tapping test and a note on sex differences. *Perceptual Motor Skills. 48,* 139–42.

Schretlen, D.J., Winicki, J.M., Meyer, S.M., Testa, S.M., Pearlson, G.D. & Gordon, B. (2009). Development, psychometric properties, and validation of the Hopkins Adult Reading Test (HART). *The Clinical Neuropsychologist*, *23* (6), 926-943.

Schretlen, D., Brandt, J., & Bobholz, J.H. (1996). (1996). Validation of the Brief Test of Attention in patients with Huntington's Disease and amnesia. *The Clinical Neuropsychologist*, 10, 90-95.

Strauss, E, Sherman, E & Spreen, O. (2006) A Compendium of Neuropsychological Tests: Administration, Norms and Commentary. Oxford: New York.

Tombaugh, T.N. (2004). Trail Making Test A and B: Normative data stratified by age and education. *Archives of Clinical Neuropsychology*, *19*, 203-214.

Corresponding author:
John P.K. Bernstein
Department of Psychology, Louisiana State University
236 Audubon Hall
Baton Rouge, LA 70803
United States of America
jberns3@lsu.edu