

Postexercise Slowing on the King-Devick Test and Longer Recovery From Sport-Related Concussion in Adolescents: A Validation Study

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Context: The King-Devick (KD) test is a rapid number-reading test that has emerging use in the assessment of sport-related concussion (SRC). Previous research suggested that healthy individuals and patients with acute concussions who had shorter recovery times (<3 weeks) demonstrated a learning effect on the KD test after mild to moderate exertion, whereas patients with longer recovery times did not.

Objective: To assess if the absence of postexertional improvement on the KD test within 10 days of concussive head injury was associated with a longer duration of recovery.

Design: Prospective cohort study.

Setting: University concussion-management clinics.

Patients or Other Participants: Male and female adolescent athletes (n = 99, aged 13–18 years) presenting within 10 days of SRC.

Main Outcome Measure(s): The KD test was administered before and after the Buffalo Concussion Treadmill Test (BCTT). Days from injury to recovery, with recovery defined as being

asymptomatic, confirmed by the assessment of a physician who was blinded to the treatment group, and the return of normal exercise tolerance on the BCTT were recorded.

Results: Participants with postexertional slowing (PES group, n = 33) had a longer duration of recovery (17 days versus 13.5 days, $P = .033$) than participants without PES (no-PES group, n = 66). At any clinic visit, PES was also associated with a relative risk of 2.36 (95% confidence interval = 1.55, 3.61; $P < .001$) of not recovering within the following week.

Conclusions: The current study validates our prior work showing that acutely concussed adolescents who did not display the typical learning effect on the KD test after the BCTT took longer to recover from SRC than those who exhibited the typical learning effect.

Key Words: Buffalo Concussion Treadmill Test, exercise intolerance, exercise testing

Key Points

- After the Buffalo Concussion Treadmill Test, acutely concussed adolescents who did not demonstrate the usual learning effect on the King-Devick test took longer to recover than those who did show the learning effect.
- Adding the King-Devick protocol to the Buffalo Concussion Treadmill Test requires minimal time and provides prognostic information that may be clinically useful in adolescents with acute concussions.

Concussions are a form of mild traumatic brain injury that have become a public health priority in recent years.¹ In the United States, an estimated 1.1 to 1.9 million sport-related concussions (SRCs) occur each year, and approximately 5% to 10% of adolescents will experience a concussion in their lifetime.¹ The current International Concussion in Sport Group guidelines² described SRC as an evolving injury in the acute phase and one of the most complex injuries to diagnose, assess, and manage. The guidelines also state that no signs, symptoms, imaging, or blood-based biomarkers can objectively diagnose concussion or establish injury severity. The typical duration of clinical recovery in concussion

is 7 to 10 days in adults and under 4 weeks in adolescents, but 10% to 30% of adolescents are estimated to take much longer to recover.²

The King-Devick (KD) test is a popular tool for the sideline identification of concussion. Authors of a systematic review and meta-analysis³ showed that longer KD test times, compared with baseline, had high sensitivity (86%) and specificity (90%) for identifying SRC. The test involves rapid naming of numbers on a series of 3 test cards of increasing difficulty, each with variable spacing between numbers. Several neurologic pathways are involved in performing the KD test.⁴ The retina forms the signals that travel via the optic nerve to the lateral geniculate nucleus

and superior colliculus. The superior colliculus is involved in saccadic eye movements, as are the frontal eye fields, supplementary eye fields, dorsolateral prefrontal cortex, parietal lobes, and deeper structures including the brainstem.⁴ Apart from visual pathways, the KD test also involves naming numbers, which engages the language center, higher-order visual center, parietal association cortex, and Broca area. Hence, the KD test also evaluates cognitive domains, such as attention, spatial and temporal orientation, and working memory.⁵

In a previous derivation study,⁶ adolescents with acute concussions (within 1 week of injury) and healthy control participants performed the KD test twice before and once after a graded treadmill test for exercise tolerance after concussion, the Buffalo Concussion Treadmill Test (BCTT). Concussed patients and healthy control individuals who recovered normally (within 3 weeks) demonstrated the typical learning effect of reduced postexercise KD time (mean improvement of 3 ± 4 seconds). However, participants who took more than 3 weeks to recover showed minimal improvement postexercise (mean = 1 ± 7 seconds), and almost half (44%) took longer to perform the post- versus pre-BCTT KD test, which is abnormal. We hypothesized that the absence of the typical improvement in KD test performance after aerobic exercise might predict delayed recovery from SRC. To validate the findings from the derivation study, we prospectively administered the KD test before and after the BCTT to a larger cohort of adolescents with acute concussions. Our primary aim was to compare the duration of clinical recovery between those who improved their post-BCTT performance and those who did not. Our secondary aim was to see if postexertional slowing (PES) on serial clinical visits predicted clinical recovery the following week (ie, recovery not since injury but since the prior clinical visit). We hypothesized that participants who did not improve post-BCTT performance would have a longer duration of clinical recovery.

METHODS

This study was part of a larger randomized controlled trial⁷ (clinicaltrials.gov identifier: NCT02710123) of subthreshold aerobic exercise treatment for acute SRC and was approved by the University at Buffalo Institutional Review Board. Participants were recruited at 3 concussion clinics in Buffalo, New York, from September 2015 to June 2018.

Participants

Male and female adolescents (aged 13–18 years) who sustained an SRC within 10 days of their initial visit and were diagnosed with concussion by experienced sports medicine physicians based on history, including a cognitive and behavioral screen and symptom questionnaire, a concussion-specific physical examination,⁸ and exercise tolerance on the BCTT, were identified.⁹ If the adolescent was eligible, a research assistant explained the study and obtained written consent and assent the same day. All patients were prescribed treatment at the initial clinic visit and followed up with their physician weekly for the first 4 weeks or until recovered, whichever came first. If the patient was not recovered by 4 weeks after injury, he or she was referred for specific therapies (eg, cervical and

vestibular). Exclusion criteria were (1) evidence of focal neurologic deficit; (2) a history of moderate or severe traumatic brain injury (Glasgow Coma Scale score ≤ 12); (3) current diagnosis of attention-deficit/hyperactivity disorder, learning disorder, depression, or anxiety or a history of more than 3 concussions because these factors are associated with delayed recovery; (4) inability to understand English; and (5) a symptom score of < 5 on the initial symptom questionnaire.

Postexertional Slowing on the KD Test

The PES group consisted of participants with any increase in total time on the post-BCTT KD test (obtained immediately after the post-BCTT 2-minute cool-down) compared with their pre-BCTT KD time. Any participant whose post-BCTT KD performance remained the same or was faster was included in the no-PES group.

Study Procedures

King-Devick Test. The KD test is a series of rapid number-naming tasks that takes less than 2 minutes to administer.³ The KD test includes 1 demonstration card and 3 visually distinct test cards of increasing difficulty that the participants read aloud. Participants were instructed to read the single-digit numbers aloud from left to right as quickly as possible, and the time to complete each individual card and number of errors were recorded. Individuals who skipped a line were asked to repeat the entire card. They started with the demonstration card to familiarize themselves with the task. The number of uncorrected errors, including omissions and misspeaks, was recorded as instructed in the KD test manual.¹⁰ Participants performed the KD test once before and once after the BCTT weekly until recovery or for 4 weeks. The KD test guidelines recommend initially administering the KD test twice and using the best result as baseline. Any worsening compared with baseline performance suggests a concussion.¹⁰ However, the guidelines do not suggest administering the KD test twice in persons who are concussed. Because we were interested in assessing the presence or absence of a typical learning effect, we administered the KD test once before and once after the BCTT and assigned participants to the PES or no-PES groups based on KD test performance at the initial visit (< 10 days since injury). The spiral-bound version of the KD test (version 1) was used because the more recent tablet version was not available at the time of the study.

Buffalo Concussion Treadmill Test. The BCTT is a graded exercise test that can reliably assess exercise intolerance after concussion and is safe to perform as soon as the day after injury.¹¹ Participants walked at an initial speed of 3.2 mph (3.6 mph if they were 5'10" or taller) at 0% incline. The incline was increased by 1° every minute for the first 15 minutes, and the speed was increased by 0.4 mph every minute thereafter. The rating of perceived exertion (Borg scale CR-15, range 6–20), symptom severity (10-point visual analog scale), and heart rate (monitored via model FIT N2965; Polar, Kempele, Finland) were recorded every minute. The test ends at either symptom exacerbation (≥ 3 -point increase from the pretreadmill visual analog scale value) or perceived exhaustion (rating of perceived exertion of 18 or more).⁹ The test was also stopped for any

visible signs of distress, such as labored gait, loss of balance, or inability to keep up with the speed of the treadmill.

Daily Symptom Reporting. Participants reported symptoms on a password-protected online data form each day between 7 PM and 10 PM until either they were cleared to return to play by the study physician or 4 weeks had elapsed, whichever came first. To ensure compliance, participants received daily e-mail or text reminders to access the online symptom questionnaire—the Sport Concussion Assessment Tool 3 Post-Concussion Symptom Scale (PCSS).¹² The PCSS is a validated 22-item questionnaire scored on a 7-point Likert scale (0–6), for a maximum possible score of 132. Symptoms on the PCSS can be separated into the following categories: physical, cognitive, sleep, and affective.¹² If, for any reason, a participant was unable to provide a daily symptom report for 3 days in a row, he or she was withdrawn from the study. Daily symptom reports are critical to determining recovery.

Oculomotor Physical Examination. A complete concussion-focused physical examination¹³ was performed at the initial clinic visit, but only the following oculomotor examination findings are presented in this study.

(a) Smooth Pursuits (Horizontal). The participant was asked to visually track an object moving slowly in the horizontal direction (20°/s) with the head kept stationary. Target movement was limited to 30° from midline to avoid eliciting end-gaze nystagmus. Abnormal eye movements, staccatic (jerking) eye motions, corrective (catch-up or back-up) saccades, loss of visual fixation, or symptoms of headache or dizziness were considered anomalous.

(b) Convergence. Convergence was measured using an accommodation ruler (model Astron ACR/21; Gulden Ophthalmics, Elkins Park, PA) with a standard single 20/30 card as the visual target. Starting at the furthest distance from the nose, the target was slowly moved toward the nose. The distance to convergence (measured to the nearest half centimeter) was recorded on report of the image doubling (not blurring of vision) or when the clinician observed loss of convergence (exophoria). Two trials were performed, and the best trial was recorded. Convergence of more than 10 cm was considered abnormal.¹⁴

(c) Repetitive Saccades (Horizontal). The physician held his or her index fingers shoulder-length apart at half an arm's length from the participant. The participant was instructed to move the eyes from 1 finger to the other in rapid succession in the horizontal visual plane up to 30 times. Abnormal responses were delayed initiation of eye movement, slow velocity, or inaccurate movements such as overshooting or undershooting with >1 refixation saccade or symptom provocation of increased headache or dizziness.

Outcomes

The primary outcome measure was median days to recovery from the date of injury. *Recovery* was defined as symptom resolution to baseline, confirmed by a normal physical examination (normal neurologic examination, including normal vestibular and oculomotor systems), and the ability to exercise to exhaustion on the BCTT without symptom exacerbation.¹⁵ *Symptom resolution* was defined

as having no symptoms or returning to the *baseline level of symptoms*, which was defined as a symptom severity score of ≤ 7 on the PCSS for 3 consecutive days. The first day of symptom resolution was considered the date of clinical recovery if it was independently confirmed by the treating physician and BCTT results. If symptom resolution preceded clinical recovery on physical examination or the BCTT (or both), then the date of medical clearance for return to play was considered the date of clinical recovery. For participants who did not recover within 30 days, the recovery date was determined through a medical records review.

Statistical Analysis

Baseline characteristics were analyzed to assess groupwise differences between the PES and no-PES groups. Groupwise differences in normally distributed continuous variables (age, days to initial visit since injury, total symptom severity score on the initial visit, symptom categories, and exercise time on the initial BCTT) were evaluated using a series of independent-samples *t* tests. We performed χ^2 tests to identify groupwise differences for sex, prior concussions, blurry vision, physical examination findings, and incidence of delayed recovery. As the main outcome measure (days to recovery) was not normally distributed, a nonparametric test of medians (Mann-Whitney) was used. Kaplan-Meier estimates of survival analysis curves were conducted for the first 14 days, and a Cox regression model was used to compare the groups with sex, initial PCSS score, and treatment interventions (aerobic exercise or placebo⁷) as covariates.

Our secondary aim was to see if the presence of PES at any clinic visit was associated with not recovering by the next clinic visit a week later. That is, if PES was present on the second clinic visit (eg, 14 days since injury), what was the likelihood that a participant would be cleared for return to play on the subsequent clinic visit (21 days since injury)? For this, we identified the second-to-last clinic visit of each participant to obtain the BCTT and KD test results from participants who were clinically recovered within the following week. For the remaining clinic visits except the last and second to last, we identified the BCTT and KD test results from participants who did not recover within the following week. A 2×2 contingency table was created with PES (*Yes/No*) and not recovered within 1 week (*Yes/No*), and the relative risk was calculated. A *P* value $< .05$ determined statistical significance, and all tests were 2 sided. Statistical analyses were performed using SAS (version 9.4; SAS Institute Inc, Cary, NC).

RESULTS

A total of 103 participants consented for the study and completed all interventions. Four individuals were removed during the analysis because the pre-BCTT or post-BCTT (or both) KD tests was not performed during the initial clinic visit; therefore, 99 participants were included in this study. Sixty-six participants remained the same or improved their post-BCTT KD test performance (no-PES group), and 33 participants had worse post-BCTT KD test times (PES group). Participant demographics for each group are presented in Table 1. With the exception of the initial PCSS symptom score (38 in the PES group and 29 in

Table 1. Participant Demographics

Demographic	Postexertional Slowing Group (n = 33)	No Postexertional Slowing Group (n = 66)	P Value
Age, y, mean \pm SD	15.70 \pm 1.7	15.26 \pm 1.7	.23
Sex, n (% of group)	42 (42) male	57 (58) male	.12
Previous concussion(s)			.77
0	16	39	
1	10	14	
2	6	10	
3	1	3	
Days since injury, mean \pm SD	4.5 \pm 3.1	5.5 \pm 2.9	.45
Prescribed subthreshold aerobic treatment, n (% of group)	16 (49)	34 (52)	.78
Initial visit Postconcussion Symptom Scale, mean \pm SD	38.4 \pm 17.9	29.2 \pm 18.2	.02
Physical symptoms ^a	14.7 \pm 6.8	12.1 \pm 8.4	.26
Cognitive symptoms ^b	8.1 \pm 5.9	5.8 \pm 5.3	.12
Sleep symptoms ^c	3.7 \pm 2.7	3.1 \pm 3.2	.33
Affective symptoms ^d	2.7 \pm 4.1	2.1 \pm 3.2	.57
Blurred vision on Postconcussion Symptom Scale, n (% of group)	12 (36)	15 (23)	.15
Physical examination, n (% of group)			
Abnormal smooth pursuits	10 (30)	26 (40)	.32
Abnormal convergence (>10 cm)	7 (21)	12 (19)	.89
Abnormal saccades	14 (43)	31 (48)	.64

^a Physical symptoms include headache, pressure in head, neck pain, nausea or vomiting, dizziness, blurred vision, and sensitivity to light or noise.

^b Cognitive symptoms include feeling slowed down, feeling like “in a fog,” “don’t feel right,” difficulty concentrating, difficulty remembering, and confusion.

^c Sleep symptoms include fatigue or low energy, drowsiness, and trouble falling asleep.

^d Affective symptoms include feeling more emotional, irritability, sadness, and nervous or anxious.

the no-PES group, $P = .021$), no differences were present for age, sex, concussion history, treatment intervention, or physical examination findings. The PES group rated their symptoms higher in all categories, including blurry vision, but the differences were not statistically significant.

The BCTT results and pre- and post-BCTT KD test times are presented in Table 2. No differences in BCTT duration or pre-BCTT KD test times were evident between groups. The no-PES group recovered faster than the PES group (17 days in the PES group versus 13 days in the no-PES group, $P = 0.033$). The Kaplan-Meier estimates of recovery appear in the Figure. The log-rank test showed a difference between groups ($\chi^2 = 4.931$, $P = .0264$). The initial-visit PCSS score was a significant covariate ($P = .005$), but sex ($P = .966$) and treatment intervention ($P = .622$) were not.

For the secondary analysis, 20 participants with PES and 69 without PES recovered within the following week, whereas 29 participants with PES and 23 without PES did not recover by the following week. The relative risk for not recovering within 1 week in the presence of PES was 2.36 (95% confidence interval = 1.55, 3.61; $P < .001$).

DISCUSSION

This study validates a previous finding⁶ that participants who did not exhibit the typical improvement in KD test time after exertion took longer to recover from SRC than those whose postexertion time improved. In addition, participants who did not show the typical improvement reported more symptoms on the initial-visit PCSS, which was significantly associated with recovery. The reasons for our results are not clear. It is possible that participants who exhibited PES experienced cognitive fatigue, which was evident only after moderate exertion, or had an exacerbation of subtle oculomotor dysfunction that was only evident on exertion. Future researchers should evaluate postexertion KD test performance in other populations and investigate the cause of PES on the KD test. Hence, by adding a reading component to a standard concussion exercise-tolerance test, we revealed subtle impairments associated with a longer recovery. The PES group did not have a higher incidence of delayed recovery than the no-PES group, so referral for early vision therapy was not yet

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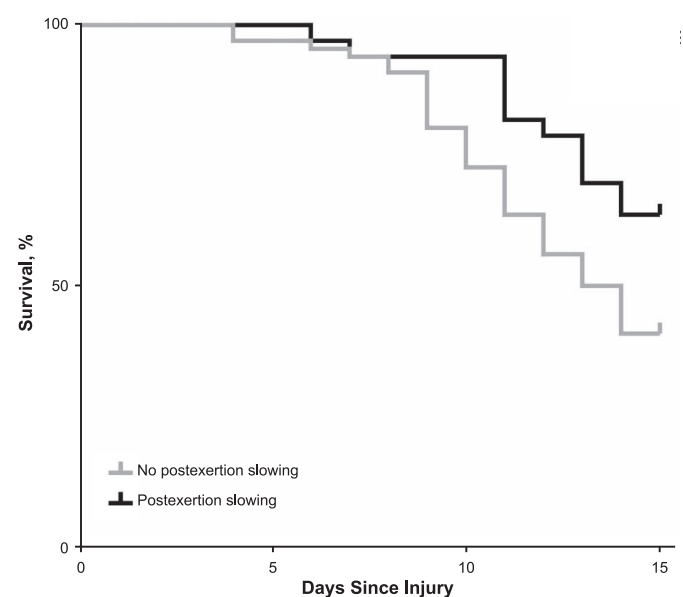


Figure. Kaplan-Meier estimates of survival for the groups with postexertional slowing and no postexertional slowing. Log-rank test $P = .0264$ ($\chi^2 = 4.931$).

Table 2. Postexertional Slowing and Duration of Recovery

Test	Group		P Value
	Postexertional Slowing (n = 33)	No Postexertional Slowing (n = 66)	
BCTT duration, min, mean \pm SD	8.94 \pm 4.7	8.92 \pm 4.7	.99
BCTT symptom exacerbation, n (% of group)	28 (84)	61 (92)	.15
Pre-BCTT King-Devick test total, s, mean \pm SD	55.4 \pm 13.9	57.0 \pm 16.2	.63
Post-BCTT King-Devick test total, s, mean \pm SD	59.9 \pm 16.2	51.4 \pm 14.4	.009
Post-pre-BCTT King-Devick test difference, s, mean \pm SD	4.5 \pm 4.5	−5.6 \pm 4.9	<.001
Median recovery duration, d (interquartile range)	17 (13–20)	13.5 (10–18.5)	.03
Incidence of persistent postconcussive symptoms (>30 d), n (% of group)	3 (9)	6 (9)	1.000

Abbreviation: BCTT, Buffalo Concussion Treadmill Test.

required. Previous authors^{16,17} suggested that poor concentration and cognitive fatigue were associated with delayed recovery from concussion. In 1 study, investigators¹⁸ reported that some concussed student-athletes who were symptom free and had returned to baseline performance on computerized neurocognitive testing at rest experienced a Postexertional decline in cognitive performance after a bout of moderate-intensity aerobic exercise. The PES and no-PES groups in our study had similar exercise-induced symptom exacerbation and oculomotor physical examination findings; however, the PES group noted more symptoms on the initial-visit PCSS. Higher initial symptom scores have been identified as the strongest predictor of delayed recovery,¹⁹ which we also observed. Yet relying on symptoms alone is problematic because of nonspecificity and large interindividual variability in symptom reporting. Certain populations are known to underreport their symptoms (eg, athletes), whereas others may overreport them (eg, persons with secondary gain), and researchers²⁰ have shown that symptom checklists may cause patients to report more symptoms versus free recall. Hence, physiological tests of oculomotor and cognitive function may help clinicians more confidently gauge the prognosis of acute concussions in adolescents.¹³ Lastly, the presence of PES at any clinic visit was associated with not recovering within the following week. This was not surprising because the presence of cognitive or oculomotor dysfunction after exertion represents ongoing cerebral dysfunction that needs to resolve before clinical recovery. The KD test time is affected by several factors, including the learning effect²¹ and the effect of exertion on cognitive speed.²² The learning effect is especially important for tests such as the KD because the scores are meant to be compared with baseline performance. Authors who assessed the test-retest reliability of the KD test (a measure of learning effect) found various results. King et al²³ administered the KD test to amateur rugby players twice in a 10-minute interval and showed a significant improvement of 5 seconds ($P < .001$). Similarly, Oberlander et al²⁴ administered the KD test on 3 days and reported a high repeatability coefficient ($r = 0.81$), a 4.3 ± 0.5 -second ($P < .001$) improvement between the first and second tests, and a 6.9 ± 0.5 -second ($P < .001$) improvement between the first and third tests. Similarly, a previous study⁶ demonstrated a mean reduction of 3.2 seconds in KD test time in healthy control individuals tested 1 week apart at rest ($P < .001$). The authors of 2 studies^{6,25} have assessed the effect of systematic exercise on the KD test in healthy controls. Lawrence et al⁶ found a mean reduction of 2.3 seconds ($P < 0.001$) after the BCTT,

and Eddy et al²⁵ described a mean reduction of 1.7 seconds after a bout of moderate exertion. However, participants who did not perform any exercise still had a mean reduction of 1.5 seconds on repeated KD tests. The authors concluded that the KD test displayed good reliability. Leong et al,²⁶ Galetta et al,²⁷ Galetta et al,²⁸ and Dhawan et al²⁹ reported mean improvements of 1 to 3 seconds in KD test performance by healthy athletes immediately after a variety of sport games, but whether this improvement was due to exertion or to a learning effect is difficult to know.

Our study had several limitations. Although we were as uniform as possible in our instructions, the KD test is effort dependent and affected by factors such as age, sex, native language, pretest exertion, sleep, motivation, learning disability, level of education, and attention-deficit/hyperactivity disorder. Except for 1 study,³⁰ whose authors assessed the effect of the environment in 9 participants, we were unable to locate other researchers who isolated the effects of distractions, environment, or the method of instruction on KD test performance. This is important because the extent to which people can focus their attention in the face of irrelevant distractions depends on the complexity of the task being performed, and maintaining attention is crucial for any concussion assessment.⁵ We used the spiral-bound version of the KD test because the study began before the computerized tablet version was released. Investigators³¹ suggested that both versions resulted in comparable performances, although they should not be used interchangeably. Lastly, we focused on a specific cohort of adolescents with SRC and, therefore, our results may not generalize to other ages, non-SRC patients, or patients with learning disorders.

CONCLUSIONS

Our findings validate prior work showing that acutely concussed adolescents who did not display the typical learning effect on the KD test after the BCTT took longer to recover from SRC than those who exhibited the typical learning effect. The mechanisms may involve cognitive fatigue, exercise-induced oculomotor dysfunction, or a combination of both. Adding the KD test to the BCTT protocol does not require much time and provides prognostic information for adolescent recovery after SRC that may be clinically useful for practitioners in the field.

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