Establishing a Baseline Score for the King-Devick Test for Concussion

A Dissertation
Presented in Partial Fulfillment of the Requirements for the
Degree of Doctor of Athletic Training
with a
Major in Athletic Training
in the
College of Graduate Studies
University of Idaho
by
Victoria L. Graham

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Authorization to Submit Dissertation

This dissertation of Victoria L. Graham, submitted for the degree of Doctor of Athletic Training with a Major in Athletic Training and titled "Establishing a Baseline Score for the King-Devick Test for Concussion," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

The dissertation is the capstone project in the Doctor of Athletic Training program. This scholarly examination of a topic of clinical interest includes manuscripts that are immediately applicable for clinicians. A thorough review of the literature on concussion assessment methods is the basis for a two-part manuscript on evidence-based best practices for concussion assessment tools commonly used by athletic trainers. A manuscript describing original research on the reliability of the method of establishing a baseline score for the King-Devick Test® for concussion is further evidence of scholarly practice.

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Selected peer-reviewed papers, posters, or lectures presented within the discipline

"Moving Beyond Rest: Targeted Treatment and Rehabilitation after Concussion," Speaker, Learning Lab at 66th NATA Annual Meeting & Clinical Symposia, St. Louis, Missouri, June 2015

Baker RT, **Graham VL**, Seegmiller JG, Nasypany A, Vella CA (June 2015): "Clinical Reaction Time is Not Significantly Affected by Moderate-Intensity Aerobic Exercise," poster presentation at 66th NATA Annual Meeting & Clinical Symposia, St. Louis, Missouri

"Ocular Issues and Concussion," podium presentation at Southeast Athletic Trainers' Association Annual Meeting, Atlanta, Georgia, March 2015

Baker RT, **Graham VL**, Seegmiller JG, Nasypany A, Vella CA: (March 2015) "Clinical Reaction Time is not Significantly Affected by Moderate-Intensity Aerobic Exercise," poster presentation at Northwest Athletic Trainers' Association (District 10), Spokane, Washington

"The Eyes Have It: Ocular Function and the Concussion Assessment," Speaker, Learning Lab at 65th NATA Annual Meeting & Clinical Symposia, Indianapolis, Indiana, June 2015

Graham VL, et al. "Exercise Does Not Affect the King-Devick Test: A Pilot Study," poster presentation at Northwest Athletic Trainers' Association (District 10), Portland, Oregon, June 2014

Baker RT, **Graham VL**, et al., "Exercise Does Not Affect Clinical Reaction Time: A Pilot Study," poster presentation at Northwest Athletic Trainers' Association (District 10), Portland, Oregon, March 2014

Brody K, **Graham VL**, et al., "Exercise Does Not Affect the Sway Balance Test: A Pilot Study," poster presentation at Northwest Athletic Trainers' Association (District 10), Portland, Oregon, March 2014

Graham VL, et al., "Exercise Does Not Affect the King-Devick, Clinical Reaction Time, or Sway Balance Tests: A Pilot Study," poster presentation at Big Sky Athletic Training and Sports Medicine Conference, Big Sky, Montana, February 2014

Invited Papers and/or lectures presented within the discipline

"Staying in the Game: Strategic Planning for State Legislative Affairs," NATA State Leadership Forum, St. Louis, Missouri June 2015

"Ocular Issues and Concussion," podium presentation at Northwest Athletic Trainers' Association (District 10), Portland, Oregon, in a session with Wilhelm J, titled: "The Latest in Concussion Evaluation and Management: Beyond the Romberg, Rest, and Gradual Return to Play," March 2014

Speaker: "Legislative Advocacy," 64th Annual NATA Meeting & Clinical Symposia, Las Vegas, Nevada, June 2013

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- "Using Clinical Trajectories to Inform Targeted Treatment Pathways with Advanced Case Studies" course (3 EBP contact hours), ImPACT Applications, January 2015
- Big Sky Athletic Training and Sports Medicine Concussion Conference (8 contact hours), Big Sky, MT, February 2014
- ImPACT Training 2-Day Workshop w/Mark Lovell & Micky Collins; (12.25 contact hours), July 2013
- Brain Injury Alliance of Connecticut Annual Symposium, Hartford, CT, (5.5 contact hours), March 2013
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- Vestibular Rehabilitation - A Comprehensive Clinical Approach for Positive Functional Outcomes, Escondido, CA, (16 contact hours), November 2013
- "Vestibular Rehabilitation: Evaluation and Treatment," North American Seminars, home study (10 contact hours), October 2013
- "Vestibular Rehabilitation: Vestibular Disorders," MedBridge (3 contact hours), June 2014
- Vestibular Rehabilitation: Office Examination of the Vestibular System; MedBridge (3.25 contact hours), May 2014

Manual Therapy (38.5 contact hours):
- Mulligan course, "Diagnosis and Treatment of the Upper and Lower Quadrant with Brian Mulligan & Kevin Wilk," Cincinnati, OH, (12 contact hours), September 2013
- Positional Release Therapy Institute: Spine and Pelvis course, Moscow, ID, (11 contact hours) July 2013
- Positional Release Therapy Institute: Lower Extremity course, Moscow, ID (11.5 contact
- hours), April 2014
- Positional Release Cranial Techniques Learning Lab, NATA Symposia, St. Louis, MO, June 2015 (2 contact hours)
- Upper Extremity Neurodynamics Learning Lab, NATA Symposia, Las Vegas, June, 2013 (2 contact hours)

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Dedication

For Patrice: thank you for your support, for making the trek cross-country, and for being there through the trials and tribulations of it all. I couldn’t have done it without you.

For my Mom, who helped me get my first library card when I wasn’t even tall enough to see over the circulation desk, for making me a reader. I’ve never quenched my thirst for knowledge…that’s a good path in life.

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CHAPTER 1

Introduction

The following professional practice dissertation is the culminating project of the Doctor of Athletic Training (DAT) program. My primary goal in the doctoral program in athletic training was to improve my ability to conduct clinical research. I came into the program with a traditional view of clinical research, and limited knowledge about action research (AR) in healthcare, and generating practice-based evidence (PBE). Like many clinicians, I was often frustrated by published studies that did not translate into clinical practice, and the limited number of applicable studies. I further recognized healthcare was changing rapidly, and understood my profession was going to need to change to stay relevant in the healthcare world. I saw the Doctor of Athletic Training (DAT) program as a means of preparing for the future.

In 2003, the Institute of Medicine (IOM) identified five core competencies for all healthcare providers, regardless of discipline, intended as a recommendation to anticipate changes necessary to meet the needs of the future .[1] This action arose from a summit examining the changing world of healthcare, and identified global deficiencies across healthcare disciplines. The Accreditation Council for Graduate Medical Education (ACGME) later identified similar concepts in six competency areas.[2] The Commission on Accreditation of Athletic Training Education (CAATE) defined six core competencies for post-professional education in athletic training analogous to those identified by the IOM and ACGME: (1) patient-centered care, (2) interprofessional education and collaboration, (3) evidence-based practice, (4) quality improvement, (5) use of healthcare informatics, and (6) professionalism.[3]

Aligned with the CAATE competencies for post- professional education in athletic training, the University of Idaho Doctor of Athletic Training (DAT) program desired to develop advanced practice clinicians in athletic training. The CAATE defines advanced clinical practice as: “the practice of athletic training at a level which requires substantial theoretical knowledge in athletic training and proficient clinical utilization of this knowledge in practice.”[3]

The DAT model encourages scholarly reflective practice with a goal of improving both the overall quality of care and individual patient outcomes. Reflecting on one’s practice is intrinsic to the DAT program and can take on many forms, including contemplating and discussing a difficult case, or actively evaluating treatment records for patterns or trends. I characterize myself as moderately reflective prior to the DAT program; however, once immersed in the program, I became more introspective about my practice and the process in which I was engaged. The lens through which I had traditionally viewed my practice was completely different. “Evidence-based practice is the integration of best research evidence with clinical expertise and patient values and circumstances to make decisions about the care of individual patients.”[4] The program has a strong focus on evidence-based practice and providing patient-centered care. Coursework and professional development activities enhance foundational and advanced knowledge, expose the clinician to multiple treatment paradigms, and require scholarly dissemination of knowledge guide participating clinicians toward creating and adopting evidence-based practice philosophies. Scholarly practitioners are able to take the appropriate steps to locate pertinent research, incorporate information with their own clinical knowledge and experience, consider the wishes and needs of the patient, and determine an appropriate course of clinical care. Evidence-based practice is integrative and requires advanced clinical reasoning skills and patient-centered care. Health care providers traditionally focused on disease-oriented evidence and care, directed and controlled primarily by the clinician. Patient-centered care encourages and empowers the patient to be an active participant in his or her own health care. The clinician is an educator and advocate for the patient, seeking the best possible course of action for the individual, based on that patient's own circumstances, values and wishes.

The term "practice-based evidence" (PBE) refers to evidence generated in clinical practice during the course of treating a patient or series of patients.[5] Clinicians develop PBE by examining and reflecting on their practice and treatment patterns to gain a stronger understanding of what constitutes patient improvement, and a positive outcome for a patient. One method of generating PBE is action research (AR), a method of combining research and practice to improve outcomes.[6] Used initially in the social sciences and education, AR has been adapted by health care practitioners to study health care administration and policy issues, and for generating PBE in their own clinical setting.[7] When clinicians are adept at identifying measures of meaningful clinical improvement within a treatment session and over time, patients ultimately receive better care with improved outcomes.[6-8] A primary focus of the DAT program is to develop clinicians skilled at incorporating AR into clinical practice, and developing PBE to be generalized and applied in clinical practice, subsequently resulting in improved patient outcomes.[9-12]

The athletic training profession needs clinicians who can function in a bi-directional research model, where research drives practice, and practice drives research.[13,14] The DAT program aims to produce advanced clinical practice athletic trainers who regularly collaborate with other disciplines, apply bench research, develop new research questions, study patient outcomes, and disseminate their findings.

The athletic trainer can set a high standard for clinical practice and encourage colleagues, employees, and students to focus on practicing a patient-centered model that values a high standard of evidence-based practice and clinical outcomes, and engaging in translational research.[9,14]

This Dissertation of Clinical Practice Improvement (DoCPI) consists of three manuscripts related to my primary clinical area of interest, sports-related concussion. A review of the literature on the most common concussion management tools used by athletic trainers is included. The Chapter Two manuscript focuses on self-reported symptoms, balance, and rapid cognitive screening. Chapter Three examines computerized neurocognitive testing, the King-Devick Test, and clinical reaction time. The manuscripts are intended to bridge the gap between clinical research and practice, and provide information about best practices and avoiding pitfalls with each of the tools most frequently employed by athletic trainers in the clinical management of concussion.

Chapter Four is a review of the literature surrounding current concussion management practices, and provides evidence of a strong foundational knowledge of current best practices in my specific area of interest. It focuses on the reliability and validity of commonly used clinical tools for concussion assessment and management.

The Chapter Five manuscript describes original research on the adequacy of the baseline testing protocol for the King-Devick Test® (K-D) for concussion, a promising yet fairly recent addition to the multi-faceted concussion assessment battery. The study is a preliminary inquiry into whether the current method of establishing a baseline score for the K-D provides a stable measure that can be reliably compared to post-injury scores. It demonstrates a scholarly contribution to the body of knowledge on concussion and has a direct effect on clinical practice.

If the present method of determining a K-D baseline score results in an unreliable time, the test may fail to identify some individuals with concussion, and in some cases, put them at risk for further injury.

I always considered myself a lifelong learner, whether related to my professional career, or a general curiosity about the world around me. As someone who started a doctoral program after greater than 25 years of clinical practice, I certainly acknowledged I wanted to expand my professional knowledge. What I didn’t fully comprehend at the start of the DAT program was how much I would learn about myself during the process, and how my concepts of my own clinical values and patient care would change.

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Chapter 2: Concussion Management: Applying Evidence to Clinical Practice, Part I

Manuscript, submitted to the *International Journal of Athletic Training and Therapy.*

Key Points

1. There is wide variability in concussion symptom reporting among healthy people.
2. The SAC is valid for assessment only 48 hours after injury.
3. Balance should be tested after a period of inactivity.
4. A complete vestibular exam contains balance, oculomotor and gait assessments.

Introduction to the Two-Part Series

Sports-related concussion has received significant attention in the medical and popular press. Individuals who return to contact sport activity before full recovery face increased risk for re-injury. Potential negative outcomes from early return are second impact syndrome, protracted recovery, long-term degenerative conditions,[1-4] mild cognitive impairment, early onset Alzheimer's disease, and chronic traumatic encephalopathy.[3-7] Symptom resolution at rest, with non-contact physical exertion, normal postural stability and normal neuropsychological status are markers for concussion recovery utilized in making return–to-play recommendations.[8-17] A multi-faceted concussion assessment battery is more effective at identifying and determining recovery than any method in isolation.[10,13,15,17] An examination of common concussion management tools is useful for clinicians making informed choices about which methods to utilize.

Factors that may negatively influence the validity of baseline scores should be considered. Additional considerations are: (1) qualifications and training needed for test result interpretation, (2) amount of time needed to administer baseline tests, (3) staffing and logistical issues at the clinical site, and (4) the expense of the tool.

Part I of this two-part series discusses self-reported symptom scales, rapid cognitive screening, and balance testing. Part II examines computerized neuropsychological testing, the King-Devick and clinical reaction time tests.

Self-Reported Symptom (SRS) Scales

There is widespread agreement among clinicians and researchers that patients should not return to physical activity with any lingering concussion symptoms.[8,10,13,17-21] Self-reported symptom (SRS) scales, a primary concussion management clinical tool, quantify complaints and can be administered quickly and easily to provide information about the patient's physical status. Six "core" SRS scales and their derivatives have been identified, and many use a seven-point Likert scale.[22,23] There is limited psychometric data (e.g., reliability, validity, sensitivity, and specificity) available on all of the commonly used SRS scales. Only the Concussion Symptom Inventory (CSI) was developed prior to its clinical use.[18,20] Clinicians must recognize specific SRS instrument limitations, the subjective nature of symptom reporting, and the tendency of athletes to underreport symptoms.[24-28] A wide range of healthy individuals (35.9-75.7%) may report concussion-like symptoms in the absence of concussion.[29-33] Females tend to endorse more symptoms than males.[34-36]

One method for improving the clinical efficacy of SRS scales is to obtain baseline scores from athletes during the pre-participation exam (PPE). Some rapid cognitive screening and computerized neurocognitive tests have SRS scales included, or a standalone version can be administered. It is important to note that exam conditions can affect the SRS report. Results of a clinical study of over 1000 college athletes indicated those with acute fatigue, illness, or orthopedic injuries at the time of testing had increased baseline SRS scores.[37] The importance of ensuring proper conditions for baseline testing (e.g., not after a workout) and postponing baseline testing for injured or ill athletes should not be underestimated. Baseline scores should be reviewed immediately after testing to ensure validity. Once the baseline SRS score is determined to be valid, a normally high baseline should be considered when reviewing the score post-injury, particularly for those with a pre-existing history of headaches, anxiety or depression.[38,39] Clinicians should avoid waiting for a "zero" SRS score when evaluating recovery from concussion, and take into consideration pre-existing symptom reports.

Rapid Cognitive Screening

Rapid cognitive screening tests are brief sideline assessments utilized to identify impairments in memory and concentration. Such tests include the Standardized Assessment of Concussion (SAC), [40,41] Sport Concussion Assessment Tool 2 (SCAT2),[18] and the SCAT3.[13,42] The Child SCAT3 is appropriate for children ages 5-12.[13] Rapid cognitive screening tests are useful at identifying the immediate effects of concussion, but are not substitutes for a thorough clinical examination or more comprehensive neuropsychological testing.

The SAC is 94% sensitive and 76% specific at differentiating concussed and non-concussed athletes and valid for identifying immediate concussion effects.[43] Perhaps the most significant limitation of the SAC is the decreased sensitivity over time; it is most useful within the first 48 hours post-injury.[44] The SCAT2 and SCAT3 include an SRS scale, modified SAC, and modified Balance Error Scoring System (BESS) test. High variability based on gender, grade, concussion history, and concentration have been found in high school athletes on baseline SCAT2 tests, [42,45] highlighting the need for accurate and valid baseline tests for later comparison.

Balance Testing

Postural control, as frequently measured in the BESS test, is an important consideration in concussion assessment.[13,21,46,47] A modified BESS test (using only a stable surface) is included in the SCAT2 and SCAT3.[42,45] Performing three trials of BESS on the same day reduces learning effects.[48,49] A modified BESS test measuring three trials of four different conditions improved reliability and ease of use.[50] For athletic trainers who must obtain baseline tests on large groups in frequently limited time, performing multiple BESS test trials may be too time-consuming to be practical; however, failure to account for learning effect results in unreliable baselines. Some clinicians film BESS tests and score them later by reviewing the film. This practice may help to improve test-retest reliability.[51] Filming allows for validity review, identifying administrator instructional errors, problems with test instructions, and improved reliability of baseline scores. A frequently overlooked issue with the BESS and other balance tests is the adverse effect of exertion on postural stability, which is negatively impacted for 13-20 minutes after exercise concludes.[52-55] Therefore, balance testing should not be employed until the patient has ceased physical activity for approximately 20 minutes.[13,56]

A promising addition to post-concussion balance evaluation is Sway Balance™ (Sway Medical, Tulsa, OK). The Sway Balance test measures thoracic postural sway using an iOS device (e.g., iPad), with an FDA-approved mobile software system that utilizes a built-in, low-power micro-electro-mechanical system (MEMS) accelerometer to estimate stability. Patients hold the device against their chests and perform a standardized static balance test protocol. Sway Balance has excellent reliability (ICC(3,1) 0.76; SEM 5.39).[57] Patterson reported a strong inverse correlation between Sway Balance and BESS scores, though the study was limited by a small number of participants (n=21).[58] There were no significant differences in a pilot study (n=30) where participants performed a ten-second static single-leg stance protocol on the Biodex Balance System SD while holding a Sway Balance device.[59] More advanced methods of assessing balance utilizing force platforms include the NeuroCom Balance Master System (Clackamas, OR) and the Biodex Balance System (Shirley, NY). NeuroCom uses the Sensory Organization Test (SOT), and Biodex uses a modified Clinical Test for Sensory Integration of Balance (mCTSIB).[60-63] Widespread use of force platform systems is limited by expense and the lack of portability to allow for testing on the sideline or at away contests.

Balance testing, as described above, evaluates the vestibulo-spinal aspect of the vestibular system. A thorough concussion assessment should further include vestibular-ocular testing, including an oculomotor exam, vestibular-ocular reflex (VOR) tests, and gait assessment. Specific tests include the Vestibular-Ocular Motor Screen (VOMS)[64] which uses a standard oculomotor exam to assess for symptom provocation, and the tandem gait task included in the SCAT-3.[42]

Conclusion

Assessing and monitoring a patient's self-reported symptoms is an important component of a comprehensive concussion management program. Baseline symptom checklists are frequently administered during baseline rapid cognitive screening or neuropsychological tests. In view of research indicating high symptom reporting in healthy subjects, it is unreasonable to expect a "zero" SRS score to mark concussion recovery. Controlling for factors including fatigue (physical and mental), illness, and stress at the time of baseline test administration will result in a more accurate baseline score, and improve the validity of symptom information when assessing the patient post-injury. The SAC, SCAT2 and SCAT3 provide important cognitive information during the initial assessment of concussion, but should not be used to track recovery over time. Balance testing with force platforms is useful but currently unrealistic for many clinicians due to equipment costs. The BESS test is a reasonable alternative, but issues with practice effects and clinician reliability in scoring the test must be addressed. Modified BESS testing can control for learning effects and decrease the amount of test time.[50] Videotaping baseline BESS tests for later clinician assessment should help improve scoring reliability, although this has not yet been studied. Advances in accelerometer technology may allow for a less subjective and more quantitative method of assessing postural stability. A key clinical point with sideline balance testing is the negative effect fatigue from exertion has on balance. Patients suspected of having a concussion should have a thorough cranial nerve assessment, including a neuro-vestibular exam with oculomotor and gait assessment, in addition to balance testing.

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Chapter 3: Concussion management: applying the evidence to clinical practice, Part II

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Key Points

1. Control for noise, distractions and overcrowding during neuropsychological baseline testing sessions.
2. Postpone baseline tests for newly injured, ill, or sleep-deprived individuals.
3. King-Devick Test is a useful addition to the sideline concussion exam.
4. Clinical reaction time is a quick, easy method of evaluating simple reaction time.

Introduction

A multi-faceted concussion assessment battery is considered to be more effective than any single method. Clinical management of concussion is evolving, and there are numerous methods available to assist in assessing the injury. Closer scrutiny of common concussion clinical management tools can help clinicians make informed choices about which methods to utilize, and provide guidance for controlling factors that may negatively influence baseline test validity. Part I of this series reviews self-reported symptom scales, rapid cognitive screening, and balance testing. Part II reviews computerized neuropsychological, clinical reaction time (RT_{clin}), and King-Devick (K-D) testing.

Computerized Neurocognitive Testing

Neurocognitive testing (NCT) has been called a "cornerstone of concussion management," and is now a standard component of the assessment battery.[1,2] NCT is most effective clinically when a valid baseline test is available for comparison. Commonly used computerized neurocognitive tests include: Axon Sports Test (formerly CogSport), Automated Neuropsychological Assessment Metrics (ANAM), Concussion Vital Signs®, and Immediate Post-Concussion Assessment and Cognitive Test (ImPACT)®. Although the tests are generally sensitive to concussion, clinicians should review the reliability and validity of the specific battery they utilize.[3-6]

It is imperative to review baseline NCT data for validity. Reports of invalid baseline test rates are highly variable, ranging from 0.4% to 30% in some studies.[7,8] Reasons for invalid outcomes include environmental distractions (e.g., noise, overcrowding), computer difficulties, and confusion about test instructions.[7,9] Individuals with learning or attention deficit disorders have a higher likelihood of invalid baseline tests.[7] Only 51.9% of athletic trainers review baseline neurocognitive test data for validity.[10] Failure to review baselines results in some baseline score data being unusable for post-injury test comparison, completely negating the testing purpose.

One common concern is that athletes will purposely attempt to score poorly, or "sandbag" their baseline neurocognitive tests, to set a lower bar for return to play decisions if they sustain a concussion. Computerized neurocognitive tests have built-in test validity measures.[8] Clinicians must be aware of cut-off scores and other red flags for invalid baselines on the neurocognitive battery they utilize.

In one study of high school athletes, 11% displayed poor effort in a test battery designed specifically to measure effort.[11] In a group of college athletes, only 10.7% of those re-taking the ImPACT battery were able to purposely score worse than their baseline, indicating how difficult it is to purposely score poorly, even with previous test battery exposure.[12] A study where one group of participants was instructed to intentionally perform poorly on ImPACT and another group was coached on the best ways to try to perform poorly further indicated the difficulty of "fooling" the test. Between 95 to 100% of participants (both coached and not coached) were detected by either ImPACT's internal validity markers or other known indicators.[13] Although many athletes may boast about intentionally performing poorly, it appears to be difficult to actually do so. It is good practice to question athletes who are vocal about sandbagging a baseline test, and they should be educated and re-tested if necessary. Test administrators can minimize invalid tests by ensuring a quiet and uncrowded test environment, educating athletes about the importance of valid baseline testing, and reducing distractions by standardizing instructions. Disruptive individuals should be asked to leave the testing area and later be tested individually.

King-Devick Test

Oculomotor dysfunction is estimated to occur in 65% to 90% of patients with traumatic brain injury.[14] Impaired saccadic eye movements were identified as evidence of suboptimal brain function after concussion and in post-concussion syndrome patients.[15,16] The K-D requires saccadic eye movements for performing rapid number naming, and evaluates language and attention. The patient is timed while reading aloud three, progressively more difficult sets of single-digit numbers.[17] The test can be administered in less than two minutes, and requires a baseline test to compare with a post-injury test. A worse (slower) score post-injury is an indication for further assessment for concussion. The K-D is an accurate sideline method for identifying concussion in mixed-martial arts, rugby, NHL players, collegiate, high school, and youth sport athletes.[17-23] According to a meta-analysis of published studies, any increase from the baseline time on the K-D indicates a five-times greater likelihood of concussion.[24] The K-D has been correlated with Standardized Assessment of Concussion (SAC) scores on the Sports Concussion Assessment Tool 2 (SCAT2),[21,23,25] and has identified unwitnessed concussions even when changes in SAC or SCAT2 scores do not exist.[18,19,21,26] In a season-long study of rugby players in New Zealand, the K-D identified 52 athletes with concussion. Only 8 of the 52 concussions were witnessed, with the 44 additional concussions detected during routine post-match K-D testing of all players, as per the research protocol.[25] K-D scores have been correlated with the visual motor speed, memory, and reaction time composite scores measured by ImPACT.[23,27] The K-D identified 79% of concussed athletes in a study of collegiate football, and women's soccer and lacrosse athletes. A combination of K-D and SAC identified 89%, while the battery of K-D, SAC and BESS identified 100% of concussed athletes.[23]

The K-D is a useful addition to the sideline concussion assessment battery. It is a simple test, completed in under a minute, and is reliable when administered even by laypeople.[28] Research is needed to understand whether the K-D can be used to track recovery over time.

Clinical Reaction Time Testing

Diminished reaction time has long been associated with concussion.[29] It may persist after symptom resolution and after patients have been cleared to resume physical activity by clinical examination.[30,31] Eckner, et al. developed a test of simple clinical reaction time using a manual visual-motor activity.[32,33] An examiner holds vertically a 1.3 m measuring stick embedded in a weighted rubber disk ("stick"). The seated patient holds his open hand at the bottom end, just above the weighted rubber disk. The examiner releases the stick in a random 2-5 second period of time, and the patient tries to catch the stick as quickly as possible (hand closure). After two practice trials, eight more trials are completed while the measurement of where the patient catches the stick is recorded for each of the eight trials. The mean RT_{clin} is calculated, as described by Eckner.[33] The RT_{clin} test has been positively correlated with, and found to be more consistent than, computerized reaction time (RT_{comp}) measured by neurocognitive testing.[32,33] The RT_{clin} test had test-retest reliability between competitive sports seasons; however, additional research is needed to determine whether a learning effect exists.[34,35] Males and females participating in exercise protocols on stationary bikes were unaffected by acute lower extremity exertion in RT_{clin} testing.[36] Additional research is needed to determine if upper extremity exertion affects the test. Limitations include the need to construct the measuring device, time required to administer 10 test trials and calculate the score. RT_{clin} may not be suitable for sideline testing in some settings.

Conclusion

Computerized neuropsychological testing is a valuable tool in the assessment of sports-related concussion. Perhaps the most important factor in the effectiveness of the test is the validity of the baseline test, regardless of the test battery in use. It is essential the testing environment be controlled for factors including noise, overcrowding, and other distractions. Individuals who are ill or injured, had inadequate sleep, or recently exercised should have testing postponed. All baseline tests should be reviewed for validity, and individuals with invalid or borderline invalid tests should be re-tested. Although the practice of "sandbagging" neuropsychological tests is significantly more difficult than most athletes believe, those who publicly boast about "fooling" the test should be questioned, educated, and re-tested. The King-Devick Test has helped identify concussed individuals in the absence of witnessed trauma, symptoms, or abnormalities on the SAC. When used as part of a test battery including the SAC and BESS, 100% of concussed patients were identified. The RT_{clin} test is an inexpensive tool that can be employed for assessing simple reaction time. Additional research is needed to determine the effects of recent upper extremity exertion on the overall reliability and validity of the RT_{clin} test.

Conclusion to the Two-Part Series

There is strong consensus a multi-faceted assessment battery should be employed when managing concussion.[2,37-43] There are numerous tools available for concussion management. Athletic trainers and team physicians should make joint decisions on choosing the most appropriate concussion management battery based on the evidence available on each measure, and considerations unique to the particular setting. Cost, staffing, time, institutional, and community resources should be taken into account.

Most tests require a baseline evaluation for optimal utilization. Invalid baseline tests are rarely the “fault” of the testing tool itself. Factors which may negatively affect baseline neurocognitive, self-reported symptom testing, and similar baseline tests must be controlled. Such factors include noisy or crowded environments, mental or physical fatigue, recent exertion, lack of sleep, illness, or pain from an injury. All baseline tests must be reviewed soon after administration, and individuals with invalid or questionable tests should be re-tested promptly. To ensure adequate time, staff, and facilities are available for administering baseline concussion tests, athletic and school administrators must be educated about the importance of a properly controlled test environment in obtaining accurate baseline measures. Furthermore, the amount of medical staff time required to administer, appropriately review all scores for validity, and re-administer baseline tests to those with invalid scores should be addressed.

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Chapter 4: Review of the Literature

Introduction

Concussion is a major public health issue, and is a particular concern at all levels of sports and recreation. The Centers for Disease Control and Prevention (CDC) estimate there are between 1.6 and 3.8 million sports-related concussions each year in the United States.[1] A concussion is defined as “a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces” and “may be caused either by a direct blow to the head, face, neck, or elsewhere on the body with an ‘‘impulsive’’ force transmitted to the head.”[2] Clinical manifestations include headache, nausea, dizziness, mental fogginess, confusion, concentration or memory problems, sensitivity to light or noise, and emotional or behavioral changes. Loss of consciousness may or may not occur.[3]

Individuals who return to physical activity, particularly contact sports, before recovering from concussion are at increased risk for re-injury and potentially catastrophic injury caused by second impact syndrome,[4] prolonged recovery from concussion,[5] and long-term degenerative conditions including chronic traumatic encephalopathy.[6,7] Retired professional football players with a history of three or more concussions are five times more likely to be diagnosed with mild cognitive impairment, three times more likely to report significant memory problems than players with no known history of concussion,[8] and have an earlier onset of Alzheimer's Disease (AD) than in the general male population in the United States. However, there was no correlation between a diagnosis of AD and the number of previous concussions.[8] The same category of football players are three times more likely to suffer from depression than similarly aged males in the general population of the U.S.[9]

The resolution of symptoms at rest, remaining asymptomatic during gradual return to non-contact physical exertion, normal postural stability, and normal neurocognitive status are considered markers for recovery and are frequently utilized when making return to play recommendations.[2,10-16] Clinical measures for assessing concussion include self-reported symptom checklists, neurocognitive testing, balance testing, saccadic eye movement testing, and reaction time testing.

Because of limitations in commonly utilized assessment tools, clinicians should use multiple measures of recovery to increase the accuracy of the final decision to allow a patient to resume unrestricted physical activity, particularly contact or collision sports.[3,12,13,15-19] Ongoing research into other concussion assessment and management tools is essential to protect the health and safety of participants in sports, active duty military personnel, and others in high risk occupations.

The King-Devick Test (K-D) is a relatively new clinical tool for concussion management. The test requires saccadic (fast) eye movements to a fixed target, for rapid number-naming, and also captures attention and language.[20] The K-D requires the individual to read aloud a series of three progressively more difficult sets of single digit numbers as quickly as possible. The K-D is scored as the time (seconds) it takes to read all three sets of numbers; the number of uncorrected errors made during the test is recorded. A baseline test is required for comparison to post-injury test scores, and takes approximately two minutes to administer. Two consecutive trials of the test are conducted; the patient must read the sets of numbers without any uncorrected errors on the baseline trials. The faster of the two baseline trials is considered the baseline score. Repeat testing is performed when a concussion is suspected. A post-injury K-D score that is higher (slower) than the baseline score, or on which the patient makes uncorrected errors, is considered an indicator of a possible concussion. The individual should then be removed from activity until examined by a qualified health care professional for confirmation of the diagnosis.

Self-Reported Symptom (SRS) Scales

There is widespread agreement that patients should not return to activity if they have any lingering symptoms of concussion. The International Consensus Statements on Concussion in Sport,[2,3,14,21] the National Athletic Trainers' Association Position Statement on Management of Sport Concussion,[19] the American Academy of Pediatrics,[15] American College of Sports Medicine, [12] American Academy of Neurology, [22] and American Journal of Sports Medicine [17] recommend patients be symptom-free prior to being cleared for return to play. The use of symptom scales as a means of quantifying patient complaints is a primary clinical tool in concussion management. SRS scales can be administered quickly and easily, and they provide important information about the patient's physical status. There are numerous self-reported symptom (SRS) scales in use, most using a 7-point Likert scale. Alla identified six "core" SRS scales and numerous derivatives currently in clinical use.[23] There is limited psychometric data (e.g., reliability, validity, sensitivity, and specificity) available on any of the commonly used SRS scales.[23,24] McLeod identified six core scales in a systematic review, finding only one of the scales, the Concussion Symptom Inventory, was developed prior to its clinical use.[24] The empirically derived Concussion Symptom Inventory (CSI) was developed after obtaining baseline symptom information from 16,350 high school and college athletes, and data from 641 athletes who subsequently sustained concussions.[25] A limitation of the study is the low number of female participants; over 90% of baselines collected were from males. [25] Both Alla and

McLeod recommended clinicians understand the limitations of SRS scales when choosing a scale to use. McLeod identified the need to develop systematically driven SRS scales.[26]

A primary benefit of SRS scales is their ease of administration. They provide important information about symptoms of possible concussion. The limitations of SRS scales in general include the subjective nature of symptom reporting, and the tendency of some athletes to underreport symptoms.[27-31] Healthy individuals (35.9-75.7%) frequently report concussion-like symptoms, and such symptoms are not unique to patients with concussion.[32-36] Females tend to report higher symptom scores than males.[37-39] Patients reporting pre-existing anxiety or depression tend to have higher SRS scores at baseline.[40,41]

Clinicians should be aware of the importance of having accurate baseline SRS data on file to better aid in clinical decision-making. Many clinicians working with athletes utilize the SRS scales included in a computerized neurocognitive test battery or the Sport Concussion Assessment Tool 3 (SCAT3) as the baseline SRS score. A study of over 1000 college-aged athletes found those who reported acute fatigue, illness, and orthopedic injuries had increased baseline SRS scores.[42] The finding indicates the importance of the timing of baseline testing (e.g., not after a workout), and the need to postpone testing for injured or ill individuals. Having an accurate SRS baseline on file for comparative purposes will greatly aid clinical decision making during the recovery process.

Rapid Cognitive Screening

Rapid cognitive screening tests are sideline assessments that use a prescribed format to measure cognitive status.[43] The Standardized Assessment of Concussion (SAC) [43,44] and the

Sport Concussion Assessment Test 2 (SCAT2) [23] and SCAT3,[3] are frequently employed rapid cognitive screening measures. The Child SCAT3 is for children between 5-12 years old.[3] Designed for ease of immediate use, rapid cognitive screening tests are not intended to be substitutes for complete clinical examinations or more comprehensive neuropsychological testing.

The SAC battery measures orientation, immediate memory, concentration, and delayed recall, and has been shown to be sensitive to identifying concussion. Athletes with concussion performed significantly worse on post-injury SAC tests in comparison to their baseline performance.[43] The SAC is 94% sensitive and 76% specific at differentiating between concussed and non-concussed athletes, and deemed valid for identifying the immediate effects of mild traumatic brain injury.[45] In a group of high school-aged participants tested at baseline and after 30 days, there was minimal learning effect for the SAC. [46] Perhaps the most significant limitation of the SAC is its decreased sensitivity over time; the SAC is most useful for identifying concussion within the first 48 hours post-injury.[8]

The SCAT3 is the third version of a rapid cognitive screening tool, which was updated in the Fourth International Consensus Statement on Concussion in Sport.[2,23] The SCAT2 and SCAT3 include a SRS checklist, Glasgow Coma Scale, Maddocks questions[47], modified SAC test, and modified BESS test. In a study where the baseline SCAT2 was administered to over 1100 high school age healthy athletes, there was variability based on gender, grade, and prior history of concussion. Males scored significantly lower than females at baseline; however, one limitation of the study is only around 20% of participants were female. [24,26,48] Jinguji administered baseline SCAT2 tests to 214 high school age athletes (females: n= 59) and found wide variability in concentration scores within the high school age population.[49] As a result, he recommended return to play decisions not be based on concentration testing without a baseline test for comparison. The modified BESS test within the SCAT2 can be affected by fatigue from physical exertion for up to 20 minutes post-exercise.[50]

Neurocognitive Testing

Neuropsychological, or neurocognitive, testing is often called a "cornerstone of concussion management."[14] Computerized neurocognitive tests (C-NCT) designed for ease of administration to athletes are in common use for concussion management. C-NCT batteries typically include measures of processing speed, reaction time, working memory, delayed recall, and impulse control. The most frequently utilized C-NCTs include the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT)®, (ImPACT Applications, Pittsburgh, PA); Axon Sports Test (formerly CogSport) (Axon Sports, Australia), the Automated Neuropsychological Assessment Metrics/Sport (ANAM), and Concussion Vital Signs® (CNS Vital Signs, LLC, Morrisville, NC). The Headminder Concussion Resolution Index is no longer available.

C-NCTs are sensitive to concussion. Broglio reported ImPACT was 79.2% sensitive, and Headminder CRI as 78.6% sensitive respectively, to concussion. [51] ImPACT had 81.9 sensitivity and 89.4 specificity. [38,52] The Automated Neuropsychological Assessment Metrics (ANAM); however, was found to have limited sensitivity to concussion, particularly more than ten days post-injury. [53] Although generally sensitive to concussion, C-NCTs have limitations clinicians should consider when selecting and utilizing such clinical tools. Broglio evaluated test-retest reliability of ImPACT, Headminder (CRI), and CogSport and reported those C-NCTs "did not provide stable measures of cognitive functioning in healthy adults." [54] One limitation of the study is the data reported was on a limited number of subjects (n=28), after other subjects were excluded for reasons including invalid baseline tests (n=40 of 68 subjects). The fact that over one half of baselines were invalid inadvertently highlights the importance of assessing baseline data for validity. Failure to do so may result in instances of clinicians having invalid baseline data for comparison to post-injury scores, completely negating the purpose of baseline testing.

Many clinicians have concerns about athletes intentionally attempting to perform poorly on baseline tests (i.e., "sandbagging"), in an effort to influence return to play decisions if they subsequently sustain a concussion. Each of the more commonly used C-NCT batteries has internal validity measures designed to identify sandbagging, as do traditional pencil and paper neuropsychological tests. In a study by Hunt, et al., high school football players took a pencil and paper neuropsychological test battery prior to the season. The test battery included two test modules designed to specifically measure effort during testing: the Rey 15 Item Test with Recognition Trial [55,56] and the Rey Dot Counting Test.[55,56] Of the high school athletes who took the neuropsychological test battery, 11% displayed poor effort, based on their performance on the Rey 15-item Recognition and Dot Counting Tests.[57] The participants who displayed poor effort had statistically significant differences in performance on neuropsychological tests. The finding again emphasizes the importance of thoroughly evaluating baseline data to identify invalid tests, and re-testing some athletes to ensure a valid baseline test is on file.

In summary, neuropsychological testing can provide valuable information about recovery from concussion. It should not be used as a standalone tool. Many of the actual and perceived problems with neuropsychological testing are a result of inadequate testing procedures including:

noisy or crowded test environments, failure to review baseline data, and not eliminating subjects who are injured, ill, or excessively fatigued.

Balance and Postural Stability

Postural control is an important consideration in concussion assessment.[3,22,58-62] The Balance Error Scoring System (BESS)[28,63-65], modified BESS[66], NeuroCom Sensory Organization Test (SOT) [59,67,68], and Biodex Balance System Clinical Test for Sensory Integration of Balance (CTSIB) [69] are the most commonly utilized measures of postural stability within a concussion assessment battery.

The BESS is frequently utilized because of the ease of administration and the minimal cost associated with it. BESS has been shown to have learning effects.[46,50,70] Three trials of BESS performed on the same day reduces the learning effect. [71,72] Hunt described a modified BESS test that measured three trials of four different conditions, and improved reliability and ease of use.[66] Finoff reported the total BESS score was not reliable, even when using clinicians experienced in scoring BESS. [73] Clinicians frequently film BESS tests when screening high numbers of athletes consecutively, and score the tests later. This method should be studied to determine if test-retest and inter-tester scoring reliability improve when the scorer is not pressured to quickly score the test.

A frequently overlooked issue related to the clinical use of the BESS and other balance tests is the adverse effect of exertion on postural stability. Postural stability is negatively affected for between 13-20 minutes after the conclusion of exercise.[50,74,75] Erkmen reported fatiguing exercise increased postural sway as measured by the BESS.[74] Fox, et al. found both aerobic and anaerobic exercise adversely affected postural stability as measured by the BESS (n=36) for up to 13 minutes after the end of activity.[75] Susco, et al. found exertion adversely affected postural control as measured by the BESS (n=100) for 20 minutes after the end of exertion.[50] Based on this evidence, clinicians should wait at least 13-20 minutes before performing BESS testing if the patient has been exercising immediately prior to the injury.

The Sway Balance Mobile Application™ (Sway Medical, Tulsa, OK) measures thoracic postural sway using the triaxial accelerometer of any iOS device (i.e., iPad, iPhone, or iTouch). The Sway Balance (SWAY) software is an FDA-approved mobile software system that utilizes a built-in, low-power micro-electro-mechanical system (MEMS) accelerometer to estimate stability by having patients hold the device against their chests and perform a standardized static balance protocol, similar to the BESS stances. Patterson reported a strong inverse correlation when comparing SWAY scores to BESS scores, though the study was limited by a small number of participants (n=21).[76] There were no significant differences in mean sway measures in a pilot study (n=30) in which participants performed a 10-second static single-leg stance protocol on the Biodex Balance System SD, while simultaneously holding a device with the SWAY program.[77] Amick reported SWAY has excellent test-retest reliability (ICC(3,1) 0.76; SEM 5.39), in a study of young adults (n =24; mean age, 25.96).[78] Further research is still needed to validate the reliability of the SWAY balance tests.

The use of force plates to measure postural sway and balance is limited by the significant expense and lack of accessibility to the equipment. Currently, they are used primarily for research and rehabilitation. Direct comparison of the most commonly used force plate systems, the NeuroCom Balance Master System (Clackamas, OR) and the Biodex Balance System (Shirley, NY), have been inconclusive to date.[79]

Clinical Reaction Time

Diminished reaction time is associated with concussion, and may persist after symptom resolution, and even after patients are cleared to resume physical activity based on a clinical examination.[80-82] Eckner, at al. developed a test of clinical reaction time (RTclin) using a manual visual-motor activity.[41,83] The testing device ("stick") is a 1.3 m measuring stick embedded in a weighted rubber disk. An examiner holds the stick upright (vertically) at the top end, with the weighted rubber disk at the bottom of the stick positioned adjacent to the seated patient's hand. The stick is released by the examiner, without warning, in a random 2-5 second period of time. The patient must grasp the stick as quickly as possible (hand closure); a total of eight trials are completed (after two practice trials). The mean RTclin is calculated by computing the measures of the point at which the patient caught the stick for each of the trials, as described by Eckner.[41] There is a positive correlation between the RTclin test and computerized reaction time (RTcomp), as measured by neurocognitive testing.[41,83] RTclin has test-retest reliability between competitive sports seasons; however, more research is needed to determine whether learning effects exist.[84] The RTclin test was not affected by acute lower extremity exertion, in a study of males and females participating in exercise protocols on stationary bikes.[85] Future research should address whether upper extremity intensive exercise affects the RTclin test.

Oculomotor Dysfunction and King-Devick Testing

Oculomotor dysfunction occurs in an estimated 65-90% of patients with traumatic brain injury.[86] Types of visual motor deficits include problems with saccades, accommodation, and smooth pursuits. Saccades are voluntary rapid eye movements. Impaired saccadic eye movements are evidence of suboptimal brain function after concussion and in patients diagnosed with post-concussion syndrome.[87-89]

The King-Devick (K-D) Test requires saccadic eye movements for performing rapid number naming, and captures impairments of eye movements, attention, and learning.[90] It was originally designed to assess oculomotor function and its relationship to reading and learning disabilities.[91,92] The K-D has been adapted for assessing neurological conditions including concussion, Parkinson's disease, multiple sclerosis, hypoxia, and sleep deprivation.[90,93-97]

The K-D can be administered in less than two minutes and requires a baseline test for comparison to a post-injury test. The patient is timed while reading aloud three, progressively more difficult sets of single-digit numbers, and a composite score (time in seconds) is recorded. A worse (slower) score on the post-injury test is an indication for further evaluation for concussion. According to a meta-analysis of published K-D studies, any increase in time compared to the baseline time on the K-D indicates a five-times greater likelihood of concussion.[98] The K-D is an accurate sideline method of identifying concussion in cohorts of mixed-martial arts, rugby, NHL ice hockey players, collegiate, high school and youth sport athletes.[20,90,99-103] K-D scores worsened (were slower) when athletes sustained a concussion. The K-D has been correlated with Standardized Assessment of Concussion (SAC) and SAC scores on the Sports Concussion Assessment Tool 2 (SCAT2).[20,103,104] It has identified concussions when changes in SAC or SCAT2 scores do not exist, and concussions not witnessed during play.[20,100,101,105] In a season-long study of rugby players in New Zealand, the K-D identified a total of 52 concussions. Only 8 of the 52 concussions were witnessed, meaning the remaining 44 concussions were identified with the K-D during routine post-match testing of all players, which was the research protocol, but not standard clinical practice.[104] K-DT scores have been correlated with the visual motor speed, visual memory, and reaction time composite scores as measured by ImPACT.[103,106] In a study of adolescent patients recovering from concussion over an extended period of time, K-D scores improved in a parallel manner with the visual motor speed, visual memory, and reaction time composite scores on ImPACT.[106] Post-exertion K-D scores were compared with baseline measures of men's intercollegiate basketball players (n=10) after they completed an intra-squad scrimmage. Players did not appear to be affected by exertion; in fact, their mean test scores improved by 3.6 s.[99] In a study of collegiate football, women's soccer and women's lacrosse athletes who sustained diagnosed concussions (n=30), the K-D identified 79% of concussed athletes.[103] When the K-D was combined with the SAC, 89% of concussed athletes were identified, when the K-D, SAC, and the BESS test were combined 100% of concussed athletes were identified.

The K-D test appears to be a reliable rapid sideline assessment tool when used with other components of a concussion assessment battery. It is a simple test completed in under a minute and does not require a medical professional to administer, making it a tool that may be used in youth sport activities that routinely lack the presence of medical personnel on the sidelines.[107] Further research about K-D testing and saccadic eye movements associated with concussion is needed to determine whether it has utility at tracking aspects of recovery over time.[17,62,106]

The Multifaceted Concussion Assessment Battery

The most commonly utilized concussion assessment tools have limitations, and none should be used as standalone tools to measure recovery from concussion or make return to play recommendations. Using a multifaceted concussion assessment battery, including some combination of the tools previously discussed, to improve the accuracy of the evaluation and guide clinical decision making is considered best practice.[10-13,15,16,23,108]

A battery of a SRS scale, BESS and SAC was 94% specific at the time of concussion, in comparison to any of those tools alone: SRS (89% specificity), BESS (34% specificity), SAC (80% specificity).[8] ImPACT had sensitivity of 81.9% and specificity of 89.4% when utilized concurrently with the symptom scores that are part of the ImPACT battery.[38] The sensitivity of ImPACT increases from 64% to 83% when an SRS scale is included with the test battery.[109] In a study of college athletes (n=30), the K-D and SAC identified 89% of concussed athletes used together; a battery of K-D, SAC and BESS identified 100% of concussed athletes.[103] A meta-analysis of concussion assessment tools found commonly utilized tools to be more effective when utilized in combination with each other, rather than individually.[110] Future research should include studies attempting to identify the most effective combinations of test batteries for both the identification of concussion and tracking recovery over time.

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Chapter 5: Establishing a Baseline Score for the King-Devick Test for Concussion

Manuscript, submitted to *Brain Injury*

Abstract

Context: The King-Devick (K-D) test is effective at identifying the immediate effects of concussion in athletes. A baseline K-D score and a post-injury K-D score are compared after a suspected concussion. If the post-injury score is worse (slower) than the baseline score, or the participant makes any uncorrected errors during the test, the individual is assessed by a medical professional for a suspected concussion. A pretest-posttest design was used to determine if two trials of the K-D test are sufficient to establish a reliable baseline score. **Methods:** College-aged (mean age 22.80 y ± 3.86 y) participants (n=35) completed two consecutive trials of the K-D test to establish a baseline score. A subset (n=20) of participants performed four additional trials of the K-D test. **Results:** Scores at Trial 1 (M = 41.72; SD = 4.67) were significantly higher (slower) than all other time points. Results indicated significant differences between Trial 1 and Trial 2 [$F(1, 34) = 15.43$, $p < .001$]. Analyses consistently suggested the first administration of the test differed from all subsequent trials. Findings suggest a two-trial administration of the K-D test may not provide a valid baseline score. A three or four trial serial administration of the K-D test may provide a more accurate assessment. **Conclusions:** A single practice trial followed by at least two consecutive trials of the K-D test may provide a more reliable baseline test score. Additional research is needed. **Keywords:** King-Devick test, concussion, saccades, vision, eye movements, oculomotor

Introduction

A concussion is a "complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces."[1] Direct contact to the head or body can result in a concussion, and there is frequently no associated loss of consciousness. The term "concussion" is used interchangeably in the literature with "mild traumatic brain injury (mTBI)." The Centers for Disease Control and Prevention (CDC) estimate there are between 1.6-3.8 million sports-related concussions each year in the United States.[2] Concussions account for 5-9% of all sports-related injuries.[1,3] Nearly one-third (30%) of head injuries seen in emergency departments in the United States result from sports or recreational pursuits.[4] Individuals who return to physical activity, particularly contact sports, before being fully recovered from concussion are at increased risk for re-injury, potentially catastrophic injury caused by second impact, and protracted recovery from concussion.[5,6] Degenerative conditions including mild cognitive impairment, early-onset Alzheimer's disease, and chronic traumatic encephalopathy are associated with repeated head trauma.[7-9] A multifaceted concussion assessment battery is considered more effective than any single assessment method in isolation.[1,10,11] In addition to the neurologic exam, frequently used clinical assessment measures include self-reported symptoms, rapid cognitive screening, balance screening, computerized neurocognitive testing, and clinical reaction time testing. There is often a delay in the presentation of symptoms after concussion, especially in athletes who are in the midst of competing or practicing when they sustain the injury. Another confounding factor is the tendency of athletes to underreport symptoms.[12-14] For these reasons, quick, accurate, and reliable objective methods are needed to identify immediately athletes who have sustained concussions.

The King-Devick (K-D) test is used to identify oculomotor dysfunction and learning related visual problems, primarily in schoolchildren.[15,16] It is also used to assess oculomotor function in patients with neurological conditions including multiple sclerosis, Parkinson's disease, hypoxia, amyotrophic lateral sclerosis, as well as extreme sleep deprivation.[17-21] The K-D test has been adapted for use as a sideline tool for identifying concussion in sports and has been reported to be an accurate sideline method for identifying concussion in cohorts of mixed-martial arts, rugby, NHL ice hockey players, collegiate, high school and youth athletes.[22-27]

Vision is associated with over 50% of the brain's neural pathways. Oculomotor dysfunction is estimated to occur in 65-90% of patients with traumatic brain injury.[28] Patients with concussion frequently have problems with saccades, pursuits, accommodation, and convergence.[29] Impaired saccadic eye movements are evidence of suboptimal brain function after concussion, and in patients diagnosed with post-concussion syndrome.[30-32] The K-D test requires saccadic eye movements to perform rapid number naming, and captures language and attention, in addition to eye movements.[22] Although a seemingly simple test, the K-D test evaluates brainstem, cerebellar, and cerebral cortex function.[29] The K-D test can be administered in under two minutes, and requires a baseline test for comparison to a post-injury test. The patient must read aloud three, progressively more difficult sets of single-digit numbers, while being timed. A summary of the time it takes to read each of the three cards (total time in seconds) is the score. A worse (slower) score on the post-injury test is an indication the individual needs further medical assessment for a concussion. According to a recent meta-analysis of published K-D test studies, any increase in time compared to the baseline time on the K-D test indicates a five-times greater likelihood of concussion.[33] The K-D test correlates with Standardized Assessment of Concussion (SAC) and SAC scores on the Sports Concussion Assessment Tool 2 (SCAT2).[24,27,34]

The K-D test can identify concussion when changes in SAC or SCAT2 scores do not exist, as well as concussions not witnessed during play.[24-27] In a season-long study of rugby players in New Zealand, a total of 52 concussions were identified through the use of the K-D test. Team personnel witnessed only 8 of the 52 concussions; routine post-match K-D testing of all players identified 44 concussions.[27] K-D test scores correlate with the visual motor speed, visual memory, and reaction time composite scores as measured by ImPACT.[35,36] In a study of adolescent patients recovering from a concussion over an extended period, K-D test scores improved in a parallel manner when compared with those ImPACT composite scores.[35] Use of the K-D identified 79% of concussed athletes in a study of collegiate football, women's soccer and women's lacrosse athletes. Use of a battery of the K-D and SAC identified 89%, and the use of a battery of K-D, SAC and BESS identified 100% of concussed athletes.[34]

Physical exertion does not appear to affect scores on the K-D test, with times generally improving when individuals are tested after exercise.[22,26] It is reliable when administered by trained laypeople.[37] In a recent meta-analysis, the sensitivity of the K-D test was reported as 86%; specificity was 90%.[33]

The K-D test for reading assessment does not require administration of a baseline test; however, a baseline test is required when using of the K-D test as a sideline assessment tool for concussion. There is no published information explaining the methodology for determining how to establish and score the baseline K-D test for concussion.

We investigated whether or not the currently recommended procedure for establishing a baseline K-D test score (i.e., the faster score of two trials of the K-D test) produces a reliable baseline score.

Subjects and Methods

Participants: A University Institutional Review Board approved this study. A total of 35 undergraduate and graduate students from classes within the University participated. Written informed consent was obtained before data collection. Participants ranged in age from 19 to 39 y (mean age 22.80 ± 3.86 y); the majority were male (n = 21, 60.0%). All participants were free of self-reported head injury, ocular or vestibular problems within the past three months. Participants had not engaged in exercise on the day of the test, as confirmed through self-reporting.

King-Devick Test: The participants read aloud three different sets of single-digit numbers, and a composite score (total time in seconds) recorded. The composite score was the summary time for reading all of three sets of numbers. During a baseline test, each set of numbers must be read aloud without any uncorrected errors (e.g., reading the wrong number, skipping a number or a line). If an individual made an uncorrected error during the baseline test, the individual was asked to repeat the test until he or she completed the baseline trial without uncorrected errors. Baseline tests were scored as the summary time for all sets of numbers read, with zero errors committed, consistent with instructions from test developer.

Testing Procedures: Two (2) consecutive trials of the laptop version of the K-D test were administered to all participants (n=35) to establish a baseline score. A subset of participants (n=20) took four (4) additional trials of the K-D test immediately after the conclusion of their respective baseline test trials. The same test administrator timed each section of the test using an external mouse and provided scripted verbal instructions to all participants.

Statistical Analyses

Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 22.0 (Armonk, NY: IBM Corps.). Before conducting the primary analyses, preliminary analyses were conducted to evaluate the state of the obtained data and test the statistical assumptions associated with primary analyses. Specifically, data were examined to test for duplicate cases, missing data, and coding/scoring errors. No such errors were identified in the data. The data were further examined to assess the normality of K-D trial scores by examining the skewness, kurtosis, and ratio of the mean to standard deviation. All data were within the acceptable limits of normality for planned analyses; therefore, no transformations or adjustments were made to the raw data.

A series of quantitative analyses were conducted to examine the reliability and utility of the K-D test. Specifically, within subjects, repeated-measures analysis of variance (RM-ANOVA), reliability analysis utilizing Cronbach's alpha and intraclass correlations (ICCs), correlations, and descriptive analyses utilizing means and standard deviations were conducted. The RM-ANOVAs were used to test for differences in scores over time within the same group of subjects. Cronbach's α was used as a measure of internal consistency based on the average correlation among items. Test-retest reliability was measured using ICCs to assess the degree to which scores on a given measure remained consistent over time when changes in scores are not expected. Lastly, means and standard deviations were computed and examined to assess the trends and patterns of performance across K-D trials.

Results

Sample Descriptive Statistics

A summary of the sample descriptive statistics for both the full (N = 35) and subsample (N = 20) are below (Table 1). Across both samples, there were nearly twice as many male participants than females. Ages among participants ranged from 19 to 39 years old. In the full sample, participants were on average 22.80 (*SD* = 3.86) years old, and 23.10 (*SD* = 4.96) years old in the subsample.

Table 1: Sample Descriptive Statistics

	Full Sample (N = 35)		Subsample (N = 20)	
	n	%	n	%
Sex				
Male	21	60.0	13	65.0
Female	14	40.0	7	35.0

	Full Sample (N = 35)	Subsample (N = 20)
Age		
Mean	22.80	23.10
SD	3.86	4.96
Min	19.00	19.00
Max	39.00	39.00

Primary Analyses

There were significant differences between scores for Trial 1 and Trial 2 for all participants (n=35), F (1, 34) = 15.43, $p < .001$, $\eta^2 = 0.312$ (Table 2). Scores were significantly lower at Trial 2 (M = 39.211, SD = 5.03) compared to Trial 1 (M = 41.05, SD = 4.91). The mean difference between these scores was 1.84 (SD = 2.78) with a 95% confidence interval ranging from 0.89 to 2.80. Participants' performance on the K-D test differed between Trial 1 and Trial 2 from 0.20 to 10.10 seconds with a mean decrease of 2.55 seconds (SD =2.12), meaning the second trial of the test was faster (better) than Trial 1. The findings suggest that two trials of the K-D test may not be sufficient to establish a baseline measure of performance, as evidenced by the statistically significant differences between scores.

Table 2: Means and Standard Deviations of Trial 1 and Trial 2 K-D Scores

	n	*M*	*SD*	*F*	*p*
				15.43	< .001
Trial 1	35	41.05	4.91		
Trial 2	35	39.21	5.03		

A within subjects RM-ANOVA was conducted to test for differences between all six trials of the K-D test, indicating a significant overall effect of trial on K-D scores, F (5, 80) = 6.58, $p < .001$, $\eta^2 = .292$ (Table 3). Multiple pairwise comparisons were examined using both parametric and nonparametric methods, due to limited sample size and other violations of parametric analyses, to determine which time points differed significantly. Scores at Trial 1 (*M* = 41.72; *SD* = 4.67) were significantly higher than all other time points. Furthermore, scores at Trial 2 (*M* = 40.06; *SD* = 5.54) were significantly higher than Trial 5 (*M* = 38.36; *SD* = 5.83). Although scores improved (faster time) after Trial 1, the differences between trials did not meet statistical significance. Although the main effect suggests significant differences across scores, these findings suggest that after Trial 1, there is not a significant practice effect of subsequent administration of the K-D test.

Table 3: Means and Standard Deviations of K-D Scores by Trial

	n	*M*		*SD*	*F*	*p*
					6.58	< .001
Trial 1	17	41.72	[a]	4.67		
Trial 2	17	40.06	[b,c]	5.54		
Trial 3	17	39.55	[b]	5.60		
Trial 4	17	39.02	[b]	6.20		
Trial 5	17	38.36	[b,d]	5.83		
Trial 6	17	38.44	[b]	6.58		

Note. Means with differing superscripts differed significantly, $p < .05$

To evaluate whether there was a difference between K-D test scores with serial administration of the test, six consecutive trials of the K-D test were administered to a sub-group of participants (n=20). Descriptive analyses were examined to assess the patterns of performance (Table 4) and evaluate whether there is a practice effect associated with serial administration of the K-D test.

As shown in Table 6, at the individual level, performance across trials fluctuated in both directions. Differences between highest and lowest scores for Trials 3 through 6 were also calculated. Participants scores varied between 1.10 and 8.70 seconds, with an average of 3.75 seconds (*SD* = 2.25).

Table 4: Individual K-D Scores by Trial

Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
52.2	42.1	50.3	46.8	42.3	46.4
41.2	39.7	41.1	40.6	40.4	43.7
36.6	33.7	--	30.6	29.2	29.3
46.8	46.0	40.4	--	44.2	42.9
54.5	48.2	--	44.6	40.4	42.4
41.9	38.0	36.4	37.1	35.3	35.9
38.8	39.0	36.1	35.3	34.4	37.2
36.9	29.7	28.0	27.9	27.4	26.8
40.6	36.4	34.9	34.8	35.2	33.3
36.8	39.0	36.4	33.7	30.5	30.3
43.2	38.3	38.9	37.0	36.4	33.7
38.2	36.8	37.4	36.8	38.3	36.5
52.1	55.1	50.8	56.2	53.6	54.9
43.2	44.2	43.7	41.3	43.8	39.8
40.2	37.9	39.2	37.9	40.6	40.5
39.7	38.3	38.5	37.1	37.8	39.2
38.7	36.2	35.9	36.0	35.3	34.7
37.1	38.8	37.8	37.8	37.3	36.2
42.4	43.2	42.9	43.2	42.8	39.6
46.1	48.3	44.0	43.8	40.7	44.8

We examined the number of trials needed to optimize the reliability of K-D test scores (see Table 5). Reliability was assessed utilizing Cronbach's α and intraclass correlations (ICCs). ICCs were tested for consistency using the two-way random model of single measures ($ICC_{2,1}$). Due to identified differences between Trial 1 and other trials, reliability was computed with and without Trial 1 scores. Reliability was acceptable across all combinations of trials (Table 5). Notably, reliability was higher when scores from Trial 1 were not included; reliability was the highest when using Trials 2 through 6 (α = .980; ICC = .910). While there was superior reliability with these measures, it is important to note that all reliability was considered strong.

Table 5: Summary of Test-Retest Reliability of K-D Trials

Trial	α	ICC*
1, 2	.915	.844
1, 2, 3	.935	.827
1, 2, 3, 4	.965	.874
1, 2, 3, 4, 5	.972	.873
1, 2, 3, 4, 5, 6	.977	.877
2, 3	.920	.851
2, 3, 4	.970	.915
2, 3, 4, 5	.976	.910
2, 3, 4, 5, 6	.980	.910

Note. ICC = Intra-class Correlation; * Two-way random model, Single Measures ($ICC_{2,1}$)

To further examine any potential learning or practice effect, individuals scores across all 6 trials were plotted, and patterns examined; see Figure 1. As shown, at the individual level, performance across trials fluctuated in both directions. Differences between highest and lowest scores for Trials 3 through 6 were also calculated. Participants' scores varied between 1.10 and 8.70 with an average of 3.75 (*SD* = 2.25).

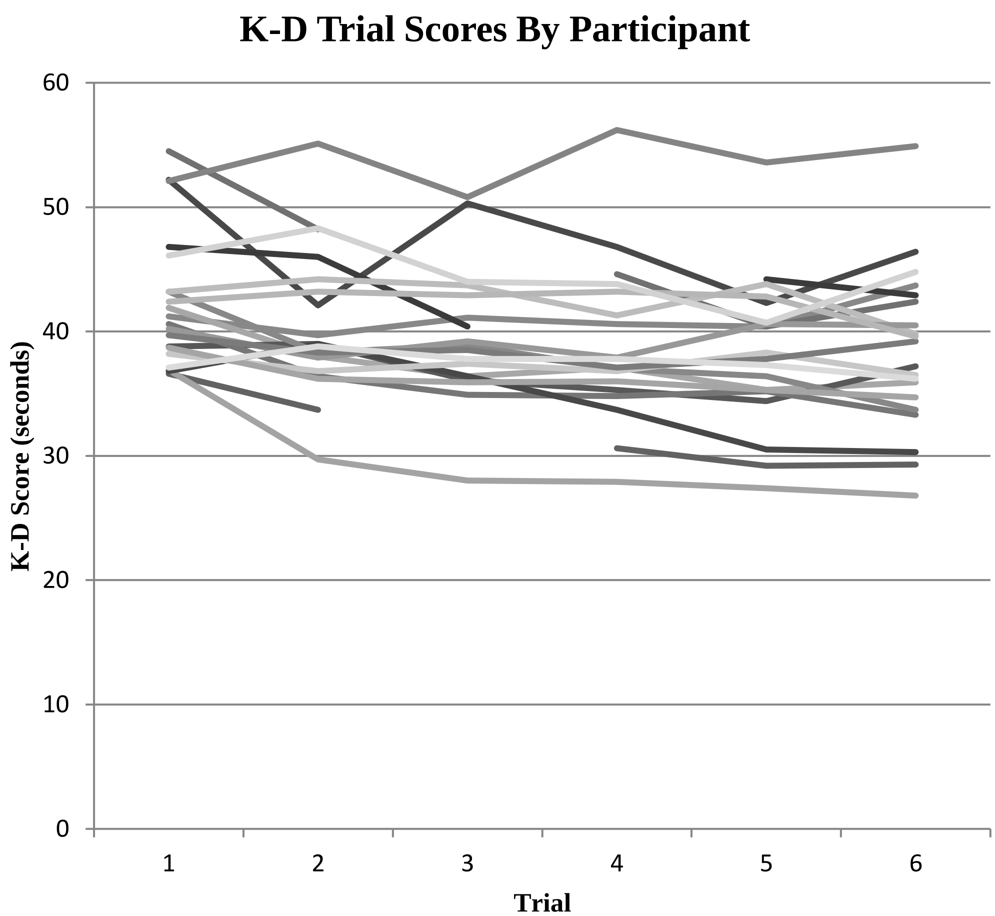

Figure 1

To assess any differences in establishing a baseline score, descriptive and difference scores were computed when using the traditional baseline procedures compared to a proposed alternative method for establishing a baseline. The traditional method for establishing a baseline K-D score consists of administering two trials, with the faster (lower) of the two scores considered the baseline score. We examined a theoretical alternative baseline method ("alternative"), consisting of an unscored practice trial, followed by three timed trials, with the fastest time of the three trials being considered the baseline score. In this study, because all trials were timed, the first trial time was simply ignored and considered the 'practice' trial for this part of the analysis. As shown below in Table 6, over half the participants (n = 13; 65.0%) had a faster (better) baseline measure when using the alternative approach. There were three participants (15.0%) who had identical baseline scores, regardless of the method used, and two participants (10.0%) who had slower (worse) scores using the alternative method of establishing a baseline. A paired-samples t-test was conducted to see if overall group level baseline scores were different, which revealed that on average, using the alternative method resulted in scores that were 1.57 seconds faster compared to the traditional method, t (19) = 4.26, $p < .001$. The small sample size (n=20) in the sub-group of participants who took serial K-D tests is a limitation in terms of generalizability. Additional research is needed to determine if the current method of establishing a baseline score provides a reliable score.

Table 6: Comparisons of the Traditional Baseline Compared to the Alternative Baseline

Case	Traditional	Alternative	Difference
7107	42.1	42.1	.0
7112	39.7	39.7	.0
7122	33.7	30.6	3.1
7123	46.0	40.4	5.6
7104	48.2	44.6	3.6
7111	38.0	36.4	1.6
7101	39.0	35.3	3.7
7102	29.7	27.9	1.8
7103	36.4	34.8	1.6
7105	36.8	33.7	3.1
7106	38.3	37.0	1.3
7108	36.8	36.8	.0
7109	52.1	50.8	1.3
7110	43.2	41.3	1.9
7113	37.9	37.9	.0
7114	38.3	37.1	1.2
7115	36.2	35.9	.3
7118	37.1	37.8	-.7
7119	42.4	42.9	-.5
7125	46.4	43.8	2.6
Mean (*SD*)	39.91 (5.27)	**38.34 (5.14)**	1.57 (1.65)

Note: Mean in boldface was significantly lower, t (19) = 4.26, $p < .001$

In order to examine any potential false-positives of the traditional K-D baseline administration, descriptive and frequency analyses were performed. Of the 20 participants in the sample who completed the serial administration of the K-D test, five (25%) had slower (worse) scores their baseline. As such, these five participants' tests can be considered to be false-positive tests using the traditional baseline procedure. Using the alternative baseline procedure, only two (10%) cases had subsequent performance of more than two seconds worse on successive administrations.

Discussion

Scores across all trials of the K-D scores were significantly and positively related, indicating that individuals tended to have similar performance on the K-D test across trials. Test-retest reliability and internal consistency of scores indicated the serial administration (i.e., 4 trials) yielded superior reliability. The results indicate the K-D test is a stable and reliable measure.

The original use of the K-D test was to identify oculomotor problems associated with reading. The K-D test for reading does not require a baseline test. The K-D reading test score is the summary time for reading aloud the set(s) of numbers, with the number of uncorrected errors (if any) recorded as part of the score. The K-D test for concussion requires the establishment of a baseline score, which is the fastest time of two consecutive trials. Each set of numbers must be read aloud without any uncorrected errors (e.g., reading the wrong number, skipping a number or a line) during the baseline test. If an individual makes an uncorrected error during the baseline test, the individual is asked to repeat the test until he or she can complete the test without errors.

Baseline tests are scored as the summary time for all sets of numbers read, with zero errors committed. We are not aware of any published studies that provide the methodology for establishing the 2-trial procedure for determining a baseline K-D score.

As with any clinical test that requires a baseline measure, the validity of the baseline score is paramount. There was a significant difference between Trial 1 and Trial 2 of the baseline administration of the K-D test in our study, with scores being significantly faster (lower) for Trial 2. What this suggests is that scores differ across the two first trials of a baseline K-D test; therefore, two trials may be insufficient to establish an accurate baseline assessment. In a study of male professional ice hockey players, Vartiainen et al.,[38] reported the second trial of a baseline test was faster in 88% of athletes tested (n=124), with a mean improvement of 2.1s. In our study, the mean improvement was 2.55 seconds during Trial 2.

The improvement between trials one and two prompted study on whether more trials would produce changes in the baseline score. Although participants' scores tended to decrease slightly with repeat administration of the K-D test, there was not a statistically significant difference between the baseline K-D and four additional post-baseline tests (K-D post) trials in this study. What this suggests is that without physical activity or injury, individuals appear to perform at a similar level on the K-D test, after the initial trial. We noted a wide standard deviation for individuals, which further indicates the need for a means of clinically interpreting seemingly minute variance in scores. For instance, if an athlete's baseline score is 37.25 seconds, is a post-injury score of 37.99 seconds clinically significant? Such questions must be answered to establish a more reliable interpretation of K-D test results.

When comparing the two-trial method with an alternate four-trial method of establishing a baseline K-D score (Table 7), we saw improvement in baseline scores of as much as 5.6 seconds (mean 1.57, 1.65) when using the four trial method. An inaccurate baseline K-D score is artificially high (slower), resulting in the possibility that post-injury testing might not identify some individuals with impairment. Previous studies have reported worsening of K-D scores after concussion ranging from 3.0s - 7.4s,[23,27,39,40] although concussed athletes in one study had K-D scores ranging from 9.5s – 44.6s[41] worse than baseline when tested at the time of injury. It is entirely possible that an athlete could be allowed to resume activity after what appears to be a "normal" K-D test, based on comparison to an artificially high baseline time.

There were three participants (across three different trials of serial administration), who made uncorrected errors on a K-D post-test, which is also considered a positive test. A single test being considered "positive" for concussion might, in some circumstances, result in removal of an athlete from activity. Although a false-positive test is not harmful to the athlete and perhaps results in a more comprehensive assessment, a test with poor specificity is impractical at best, particularly in the context of removal from competitive sports. Given the fact that some individuals must repeat the K-D baseline test more than two times to establish a baseline test score with no uncorrected errors, it is questionable whether a single error on a test should be considered a "positive" test. Additional research is needed to establish the clinical relevance of errors. For instance, is an athlete whose score is faster than baseline, but who makes a single error on a sideline K-D test impaired? Should he or she be removed from activity based on the error, despite a faster score?

From this preliminary data, the K-D appears to be a stable and reliable test. The two trial method of establishing a baseline test appears not to be the best approach. A single practice trial followed by at least two additional tests may provide a more stable assessment of baseline performance compared to the current two-trial administration. The primary limitation of this preliminary study is the small sample size. The study may not be generalizable, and further studies with larger sample sizes are needed to confirm some of the analyses conducted. Further research is needed to determine the number of trials needed to establish an accurate K-D baseline score.

Summary

Using a sample of 35 healthy participants, results suggest that the two-trial administration of the K-D test may not provide a sufficiently accurate estimate of functioning to establish a baseline score. Analyses consistently suggested that the first administration of the K-D differed from all subsequent trials, suggesting the need for at least one practice trial prior to baseline testing. Lastly, based on the current analysis, there does not appear to be a significant practice effect of a serial administration of K-D trials. Future research is needed to determine best practices for determining a baseline K-D test score, reliable change index, and minimal clinically important change.

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