Baseline Testing Protocol & Supporting Evidence.

Purpose:

Resolution of symptoms following concussion is a poor indicator of brain recovery (1). Concussion results in metabolic disturbance, changes in cerebral blood flow and perfusion, and a number of other pathophysiologic processes known as the Neurometabolic Cascade of concussion (2–4). Numerous studies show that prior to full metabolic recovery from a concussion, the brain is extremely vulnerable, where even smaller impacts can cause secondary concussion injuries and these injuries can result in severe brain injury with potentially permanent or fatal outcomes (5,6). The most important aspect to safe and proper management of concussions is to ensure that complete recovery of the brain has been achieved prior to allowing an athlete to return to a high-risk sport environment; a process which has been shown to take at least 3 to 4 weeks in adults and has an unknown timeline for children and adolescents (7,8).

Relying on the resolution of self-reported symptoms, to make return-to-play decisions puts healthcare practitioners in an extremely precarious position, as symptoms do not reflect true recovery of the brain following concussion. Self-reported symptoms at rest are even more unreliable as ongoing blood-flow and cognitive abnormalities may only come to light when challenged by intensive physical exertion tests (9–14).

Pre-season baseline testing involves testing high-risk athletes prior to starting their sporting season to assess numerous physical and cognitive systems that could potentially become affected by a concussion. When properly used and interpreted, baseline testing adds useful information to the management of sport-related concussion by giving clinical insight into pre-injury physical and cognitive functioning, which provides clinicians with objective data to make more informed and safer, return-to-play decisions (15–17). In fact, annual baseline testing is endorsed, recommended, or considered to be helpful for appropriate concussion care by most leading global health and medical groups, and position statements including: the International Consensus Statement on Concussion in Sport (16), the Centers for Disease Control (CDC) (https://www.cdc.gov/headsup/basics/baseline_testing.html), the National Athletic Trainers Association (18), The Canadian Olympic and Paralympic Concussion Guidelines (19), Concussion in Sport Australia Position Statement (20), the International Ice Hockey Summit (21), and the Canadian Academy of Sport and Exercise Medicine (22).

It should be noted that baseline testing should involve more than just computerized neurocognitive measures (23–25) due numerous reliability and validity concerns (26–28). Additionally, neurocognitive tests, in isolation, don't measure important aspects of concussion injuries such as balance, visual tracking and processing speed, strength & physical performance measures, auditory memory & concentration. A proper baseline assessment should involve all of these areas, including neurocognitive testing parameters for improved diagnostic and management utility (29–31).

COMPLETE CONCUSSIONS

This document covers all aspects of the baseline testing protocol used by Complete Concussions and provides supporting evidence for each test included within our testing battery.

Overview of the Complete Concussions baseline test protocol:

Complete Concussions offers a service to physicians by conducting comprehensive preseason testing, as well as return-to-play management, multistage physical exertion tests, and re-testing of injured individuals. All of this information can be provided to the overseeing physician in a detailed report; providing additional insight to make safer return to sport clearance decisions.

The Complete Concussions baseline testing battery takes roughly 30 minutes per individual and costs around $60 to $100. In some cases, testing may be covered under health insurance benefits. All test results are stored on a secure electronic health records system that is accessible by any Complete Concussions clinic worldwide.

Our testing protocol consists of the following areas:

- Concussion history, medical history, learning disabilities, psychiatric history
- Symptom score
- Orientation
- Auditory Memory
- Concentration
- Visual tracking and processing speed
- Balance (sideline measure)
- Postural sway using force plates
- Reaction Time
- Delayed Recall
- DANA neurocognitive testing
    - Simple Reaction Time Visual Memory Search
    - Choice Reaction Time
    - Go No Go
    - Match to Sample
    - Visual Memory Search
    - Spatial Discrimination
    - Code Substitution

***Note: Re-testing prior to return to play also involves physical exertion testing immediately prior to conducting the baseline re-assessment. This method (testing in a physically exerted state), has been shown to be a more sensitive way of testing, revealing up to 28% more neurocognitive impairment than neurocognitive testing at rest (12,14).

Symptom Score

The Post-Concussion Symptom Score (PCSS) is the most widely used concussion symptom inventory worldwide. Adapted by the Concussion in Sport Group as part of the Sideline Concussion Assessment Tool (SCAT), the PCSS is a 22-item measure with each symptom scored on a 7-point Likert scale (16). A study by Barr et al., found that the PCSS demonstrated the most sensitive and specific measure for concussion at the time of injury (when compared to balance and a neurocognitive examination), however, this score tends to normalize prior to full metabolic and functional brain recovery (32),(7). This indicates that the symptom score, while potentially the most useful parameter for making the initial diagnosis, does not coincide with the recovery of the brain following concussion. Therefore, more objective testing parameters are required to inform safer return-to-play decision-making.

Standard Assessment of Concussion (SAC)

Another component of the SCAT, the SAC is a verbal/auditory neurocognitive test, which consists of Orientation, Immediate Memory, Concentration, and Delayed Memory Recall Tests. The SAC has been validated in several studies for use in the assessment of sport-related concussion (33–35). Because the SAC does not yet have established normative data, this test must be administered at baseline to establish individualized scores. Barr & McCrea found that immediate SAC scores decrease in concussion patients by an average of 4 points from baseline. Using multiple regression, the authors found that a 1-point decrease from baseline SAC carried a 94% sensitivity and 76% specificity for the diagnosis of concussion (36). This test has also been found to demonstrate objective impairment in individuals reporting a complete resolution of symptoms (32). Marinides et al., found that the SAC alone was only able to accurately diagnose concussion 52% of the time, however adding in balance assessments and the King-Devick test improved the diagnostic accuracy to 100% (37), demonstrating the importance of a multifaceted approach.

King-Devick Test

Originally developed for the assessment of dyslexia, the King-Devick (K-D) test has emerged as one of the most popular and useful baseline and post-injury tests for concussion. The K-D test is an easily administered test for visual tracking and processing speed. Dhawan et al., found that following a concussion, there is an average drop in total reading time from baseline by 7.3 seconds. These deficits also typically remain beyond the symptomatic period, which makes the K-D test not only a good immediate sideline test, but also a good return-to-play assessment measure (38). Marinides et al., found that the K-D test alone was able to pick up 79% of concussion injuries and when combined with balance and SAC testing, 100% of concussions were accurately diagnosed (37). In ages 8 through to adulthood, the King-Devick test is able to distinguish healthy vs. concussed individuals with high accuracy and moderate test-retest reliability when a baseline test is used as comparison (40–49). As with all concussion tests, the accuracy improves when used as part of a larger testing battery.

Balance Assessment

Complete Concussions performs a two-part balance assessment, which consists of the Balance Error Scoring System (BESS) from the SCAT as well as a more objective measure of postural sway utilizing force-plate technology.

The BESS test has been studied extensively in the concussed population (34,50–52). Research in this area has found that the range of baseline scores in healthy individuals is quite wide and also age dependent, making generalizability of normative data questionable (53,54). This test has been shown to be most useful for acute concussion, as scores tend to normalize within 3 days from injury (50,55,56). As such, the Complete Concussions program utilizes a secondary balance assessment examining center of pressure measurements via force-plate technology. Force-plates demonstrate balance deficits in concussed patients beyond resolution of symptoms, SAC scores, BESS, and computerized neurocognitive test scores; demonstrating added sensitivity to the overall concussion test battery (50,57–59) . Postural sway measures using force-plates also demonstrate high test-retest consistency in adolescent athletes (60).

Clinical Reaction Time

A meta-analysis of 60 studies published in 2020 found significant reaction time deficits in the acute post-concussion phase and demonstrated a medium effect size for deficits up to 59 days post-injury (61). The clinical reaction time test is easily administered in a seated position using the athlete's non-dominant hand to grasp a dropped measuring stick with a standardized weight and spacer. This test has been found to show immediate deficits following concussion when compared to baseline and has been validated against both computerized neurocognitive measures (62–65) as well as a 'functional head protective response' (the ability for an athlete to react to and protect their head from impact) (66). The clinical reaction time test has moderate test-retest reliability over 1 to 2 years (67) with minimal practice or learning effects (68) making it an excellent test for detecting reaction time changes post-concussion.

Neurocognitive Testing

Neurocognitive testing has been a cornerstone to concussion evaluation and involves testing various domains such as reaction time, executive function, processing speed, and cognitive efficiency. As mentioned previously, neurocognitive testing is never meant to be used in isolation (27,69), however it is an important tool due to the ability to demonstrate ongoing impairment beyond symptom and other baseline test normalization (70).

Complete Concussions uses the Digital Automated Neurobehavioral Assessment (DANA) which was commissioned and studied by the US military specifically for use in a variety of field conditions. This is a mobile-optimized neurocognitive test which has been made available within our Concussion Tracker application for both pre- and post-injury testing. The included tests were selected by a scientific advisory group comprised of military and civilian neuropsychologists and neurologists. All tests included in the DANA battery were in the public domain and have extensive literature supporting their reliability and validity for traumatic brain injury.

The DANA tool has demonstrated high test-retest reliability across various testing, environmental, and temperature conditions (71–73). DANA has also been validated for the detection of concussion (74) and found in head-to-head studies to be equal to (75), or superior to (71), other neurocognitive tests on the market for the detection of concussion beyond symptom resolution (76).

Two recent studies have also found that high-intensity physical exertion, completed prior to test administration effects neurocognitive function (12,14). As such, the current recommendation is to perform neurocognitive testing following intensive physical exertion when making return-to-play clearance decisions, as this may be a more sensitive measure of ongoing cognitive deficits. In lieu of these studies, Complete Concussions clinics perform our entire testing battery following the completion of the Gapski-Goodman physical exertion test (13) prior to making return-to-play clearance decisions. Athletes must remain symptom free throughout the duration of the Gapski-Goodman Test (GGT) as well as complete ALL physical and cognitive measures to a level at or above their pre-season baseline test results immediately following the GGT.

Baseline and Concussion Management Summary

Complete Concussions was developed out of the necessity to provide high-risk athletes with evidence-based concussion management strategies. The baseline testing protocol was developed through years of research to establish the most comprehensive testing battery to assess both acute injuries and the readiness to return to high-risk sporting activities.

It has been well established through the literature that symptoms alone do not reflect true recovery of the brain, making it imperative that objective measures be incorporated into the decision-making process. In addition to this, healthcare practitioners often face pressure from athletes, parents, and coaches to provide clearance. Having rigorous, objective testing parameters can relieve this pressure and provide the clinician with the needed evidence to hold an athlete back from an early return to competition.

As was demonstrated above, no single concussion test is adequate to be used in isolation for either diagnosis or return-to-play decision-making. The Complete Concussions protocol conducts the most extensive concussion baseline testing available. Clearance of any athlete is not granted until there is a complete return to baseline of ALL measures following the passing of all step-wise return-to-learn and return-to-play stages including a 2-step process of physical exertion testing.

Referrals:

If you would like to learn more about how Complete Concussions baseline testing can help your patients or how we can help with return to school, work, and sport, or rehabilitation for persistent concussion symptoms please visit CompleteConcussions.com.

You can also download our PDF referral form here: http://completeconcussions.com/for-physicians/.

References:

1. Kamins J, Bigler E, Covassin T, Henry L, Kemp S, Leddy JJ, et al. What is the physiological time to recovery after concussion? A systematic review. British Journal of Sports Medicine. 2017 May 31;51(12):935–40.

2. Giza CC, Hovda DA. The Neurometabolic Cascade of Concussion. Journal of Athletic Training. 2001 Sep;36(3):228–35.

3. Giza CC, Hovda DA. The New Neurometabolic Cascade of Concussion. Neurosurgery. 2014 Oct;75(5):S24–33.

4. Signoretti S, Lazzarino G, Tavazzi B, Vagnozzi R. The Pathophysiology of Concussion. PM&R. 2011 Oct;3(10):S359–68.

5. Vagnozzi R, Tavazzi B, Signoretti S, Amorini AM, Belli A, Cimatti M, et al. Temporal Window of Metabolic Brain Vulnerability to Concussions: Mitochondrial-Related Impairment—Part I. Neurosurgery. 2007 Aug;61(2):379–89.

6. Vagnozzi R, Signoretti S, Tavazzi B, Floris R, Ludovici A, Marziali S, et al. Temporal Window of Metabolic Brain Vulnerability to Concussion: A Pilot 1H-Magnetic Resonance Spectroscopic Study in Concussed Athletes—Part III. Neurosurgery. 2008 Jun;62(6):1286–96.

7. Vagnozzi R, Signoretti S, Cristofori L, Alessandrini F, Floris R, Isgro E, et al. Assessment of metabolic brain damage and recovery following mild traumatic brain injury: a multicentre, proton magnetic resonance spectroscopic study in concussed patients. Brain. 2010 Oct 28;133(11):3232–42.

8. Lazzarino G, Vagnozzi R, Signoretti S. The importance of restriction from physical activity in the metabolic recovery of concussed brain. Brain Injury. 2012;

9. Baker JG, Freitas MS, Leddy JJ, Kozlowski KF, Willer BS. Return to full functioning after graded exercise assessment and progressive exercise treatment of postconcussion syndrome. Rehabilitation Research and Practice. 2012;2012(2):705309–7.

10. Leddy JJ, Baker JG, Kozlowski K, Bisson L, Willer B. Reliability of a Graded Exercise Test for Assessing Recovery From Concussion. Clinical Journal of Sport Medicine. 2011 Mar;21(2):89–94.

11. Len TK, Neary JP. Cerebrovascular pathophysiology following mild traumatic brain injury. Clinical Physiology and Functional Imaging. 2010 Nov 15;296(Suppl. 43):no-no.

12. Whyte EF, Gibbons N, Kerr G, Moran KA. Effect of a High-Intensity, Intermittent-Exercise Protocol on Neurocognitive Function in Healthy Adults: Implications for Return-to-Play Management After Sport-Related Concussion. Journal of Sport Rehabilitation. 2015 Dec 3;16:2014–0201.

13. Marshall CM, Chan N, Tran P, DeMatteo C. The use of an intensive physical exertion test as a final return to play measure in concussed athletes: a prospective cohort. The Physician and sportsmedicine. 2018 Oct 29;22(3):1–9.

14. McGrath N, Dinn WM, Collins MW, Lovell MR, Elbin RJ, Kontos AP. Post-exertion neurocognitive test failure among student-athletes following concussion. Brain Injury. 2012 Dec 19;27(1):103–13.

15. Vartiainen MV, Holm A, Lukander J, Lukander K, Koskinen S, Bornstein R, et al. A novel approach to sports concussion assessment: Computerized multilimb reaction times and balance control testing. Journal of Clinical and Experimental Neuropsychology. 2015 Dec 8;38(3):293–307.

16. McCrory P, Meeuwisse W, Dvořák J, Aubry M, Bailes J, Broglio S, et al. Consensus statement on concussion in sport-the 5th international conference on concussion in sport held in Berlin, October 2016. British Journal of Sports Medicine. 2017 Jun;51(11):838–47.

17. Henry LC, Elbin RJ, Collins MW, Marchetti G, Kontos AP. Examining Recovery Trajectories After Sport-Related Concussion With a Multimodal Clinical Assessment Approach. Neurosurgery. 2016 Feb;78(2):232–41.

18. Broglio SP, Cantu RC, Gioia GA, Guskiewicz KM, Kutcher J, Palm M, et al. National Athletic Trainers' Association Position Statement: Management of Sport Concussion. Journal of Athletic Training. 2014 Mar;49(2):245–65.

19. Benson B, Leclerc S, Richards D, McCluskey P, McCormack R, Wilkenson M, Kolb J - Canadian Olympic and Paralympic Sport Institute Network Concussion Guidelines 2018 - https://sirc.ca/wp-content/uploads/2019/12/2018-COPSI-Network-Concussion-Guidelines-EN.pdf

20. Elkington LJ, Hughes DC. Australian Institute of Sport and Australian Medical Association position statement on concussion in sport. 2017.

21. Smith AM, Alford PA, Aubry M, Sports BBC, 2019. Proceedings from the Ice Hockey Summit III: Action on Concussion.

22. Canadian Academy of Sport and Exercise Medicine Response Statement to Parachute Canada regarding Baseline Testing - https://casem-acmse.org/wp-content/uploads/2018/06/CASEM-response-to-Parachutes-Baseline-statement-final-003.pdf

23. Broglio SP, Macciocchi SN, Ferrara MS. Neurocognitive performance of concussed athletes when symptom free. Journal of Athletic Training. 2007 Oct;42(4):504–8.

24. Klossner D. 14 NCAA Sports Medicine Handbook . Indianapolis, IN: National Collegiate Athletic Association, 2013..

25. Kontos AP, Sufrinko A, Womble M, Kegel N. Neuropsychological Assessment Following Concussion: an Evidence-Based Review of the Role of Neuropsychological Assessment Pre- and Post-Concussion. Current Pain and Headache Reports. 2016 Apr 20;20(6):250.

26. Broglio SP, Ferrara MS, Macciocchi SN, Baumgartner TA, Elliott R. Test-retest reliability of computerized concussion assessment programs. Journal of Athletic Training. 2007 Oct;42(4):509–14.

27. Resch J, Driscoll A, McCaffrey N, Brown C, Ferrara MS, Macciocchi S, et al. ImPact Test-Retest Reliability: Reliably Unreliable? Journal of Athletic Training. 2013 Jul;48(4):506–11.

28. Davis GA, Anderson V, Babl FE, Gioia GA, Giza CC, Meehan W, et al. What is the difference in concussion management in children as compared with adults? A systematic review. British Journal of Sports Medicine. 2017 May 31;51(12):949–57.

29. Broglio SP, Katz BP, Zhao S, McCrea M, McAllister T, Investigators CC. Test-Retest Reliability and Interpretation of Common Concussion Assessment Tools: Findings from the NCAA-DoD CARE Consortium. Sports medicine (Auckland, NZ). 2018 May;48(5):1255–68.

30. Echemendia RJ, Iverson GL, McCrea M, Macciocchi SN, Gioia GA, Putukian M, et al. Advances in neuropsychological assessment of sport-related concussion. British Journal of Sports Medicine. 2013 Mar 11;47(5):294–8.

31. Garcia GGP, Broglio SP, Lavieri MS, McCrea M, McAllister T, Investigators CC. Quantifying the Value of Multidimensional Assessment Models for Acute Concussion: An Analysis of Data from the NCAA-DoD Care Consortium. Sports medicine (Auckland, NZ). 2018 Jul;48(7):1739–49.

32. McCrea M, Barr WB, Guskiewicz K, Randolph C, Marshall SW, Cantu R, Onat JA, Kelly JP. Standard regression-based methods for measuring recovery after sport-related concussion. J Int Neuropsychol Soc. 2005 Jan;11(1):58-69.

33. Naunheim RS, Matero D, Fucetola R. Assessment of Patients With Mild Concussion in the Emergency Department. J Head Trauma Rehab. 2008;23(2):116–22.

34. McCrea M, Guskiewicz KM, Marshall SW, Barr W, Randolph C, Cantu RC, et al. Acute Effects and Recovery Time Following Concussion in Collegiate Football Players. JAMA. 2003 Nov 19;290(19):2556.

35. McCrea M. Standardized Mental Status Testing on the Sideline After Sport-Related Concussion. J Athl Training. 2015 Jul 4;36(3):274–9.

36. Barr WB, McCrea M. Sensitivity and specificity of standardized neurocognitive testing immediately following sports concussion. Journal of the International Neuropsychological Society. 2001 Sep;7(6):693–702.

37. Marinides Z, Galetta KM, Andrews CN, Wilson JA, Herman DC, Robinson CD, et al. Vision testing is additive to the sideline assessment of sports-related concussion. Neurology: Clinical Practice. 2015 Feb 16;5(1):25–34.

38. Dhawan PS, Leong D, Tapsell L, Starling AJ, Galetta SL, Balcer LJ, et al. King-Devick Test identifies real-time concussion and asymptomatic concussion in youth athletes. Neurology Clin Pract. 2017;7(6):464–73.

39. Seidman DH, Burlingame J, Yousif LR, Donahue XP, Krier J, Rayes LJ, et al. Evaluation of the King–Devick test as a concussion screening tool in high school football players. Journal of the Neurological Sciences. 2015 Sep;356(1–2):97–101.

40. Leong DF, Balcer LJ, Galetta SL, Evans G, Gimre M, Watt D. The King–Devick test for sideline concussion screening in collegiate football. Journal of Optometry. 2015 Apr;8(2):131–9.

41. Galetta KM, Morganroth J, Moehringer N, Mueller B, Hasanaj L, Webb N, et al. Adding Vision to Concussion Testing. Journal of Neuro-Ophthalmology. 2015 Sep;35(3):235–41.

42. Galetta KM, Brandes LE, Maki K, Dziemianowicz MS, Laudano E, Allen M, et al. The King–Devick test and sports-related concussion: Study of a rapid visual screening tool in a collegiate cohort. Journal of the Neurological Sciences. 2011 Oct;309(1–2):34–9.

43. Anderson HD, Biely SA. Baseline King–Devick scores for adults are not generalizable; however, age and education influence scores. Brain Injury. 2017 Aug 22;31(13–14):1813–9.

44. Oberlander TJ, Olson BL, Weidauer L. Test-Retest Reliability of the King-Devick Test in an Adolescent Population. Journal of Athletic Training. 2017 May;52(5):439–45.

45. Naidu D, Borza C, Kobitowich T, Mrazik M. Sideline Concussion Assessment: The King-Devick Test in Canadian Professional Football. Journal of Neurotrauma. 2018 Apr 30;neu.2017.5490.

46. Arca K, Starling A, Acierno M. Is King-Devick Testing, Compared With Other Sideline Screening Tests, Superior for the Assessment of Sports-related Concussion?: A Critically Appraised Topic. Neurologist 2020 Mar;25(2):33-37.

47. Elbin RJ, Schatz P, Mohler S, Covassin T, Herrington J, Kontos AP. Establishing Test–Retest Reliability and Reliable Change for the King–Devick Test in High School Athletes. Clinical Journal of Sport Medicine. 2019 Nov;1–5.

48. Breedlove KM, Ortega JD, Kaminski TW, Harmon KG, Schmidt JD, Kontos AP, et al. King-Devick Test Reliability in National Collegiate Athletic Association Athletes: A National Collegiate Athletic Association–Department of Defense Concussion Assessment, Research and Education Report. Journal of Athletic Training. 2019 Oct 16;1062-6050-219-18-6.

49. Gubanich PJ, Gupta R, Slattery E, Logan K. Performance Times for the King-Devick Test in Children and Adolescents. Clinical Journal of Sport Medicine. 2019 Sep;29(5):374–8.

50. Riemann BL, Guskiewicz KM. Effects of mild head injury on postural stability as measured through clinical balance testing. Journal of Athletic Training. 2000 Jan;35(1):19–25.

51. Putukian M. Clinical Evaluation of the Concussed Athlete: A View From the Sideline. Journal of Athletic Training. 2017 Mar;52(3):236–44.

52. DaCosta A, Crane A, Webbe F, LoGalbo A. Change in Balance Performance Predicts Neurocognitive Dysfunction and Symptom Endorsement in Concussed College Athletes. Archives of Clinical Neuropsychology. 2020 May 15;26(1):46–8.

53. Snyder AR, Bauer RM, Network HI for F. A Normative Study of the Sport Concussion Assessment Tool (SCAT2) in Children and Adolescents. Clinical Neuropsychologist. 2014 Sep 15;28(7):1091–103.

54. Jinguji TM, Bompadre V, Harmon KG, Satchell EK, Gilbert K, Wild J, et al. Sport Concussion Assessment Tool – 2: Baseline Values for High School Athletes. British Journal of Sports Medicine. 2012 Mar 22;46(5):365–70.

55. Murray N, Salvatore A, Powell D, Reed-Jones R. Reliability and Validity Evidence of Multiple Balance Assessments in Athletes With a Concussion. Journal of Athletic Training. 2014 Aug;49(4):540–9.

56. Buckley TA, Oldham JR, Caccese JB. Postural control deficits identify lingering post-concussion neurological deficits. Journal of Sport and Health Science. 2016 Mar;5(1):61–9.

57. Slobounov S, Slobounov E, Sebastianelli W, Cao C, Newell K. Differential Rate of Recovery in Athletes after First and Second Concussion Episodes. Neurosurgery. 2007 Aug;61(2):338–44.

58. Slobounov S, Gay M, Johnson B, Zhang K. Concussion in athletics: ongoing clinical and brain imaging research controversies. Brain Imaging and Behavior. 2012 Jun 5;6(2):224–43.

59. Buckley T, Murray NG, Munkasy BA, Oldham JR, Evans KM, Clouse B. Impairments in Dynamic Postural Control Across Concussion Clinical Milestones. Journal of Neurotrauma. 2020 Jul 16;neu.2019.6910-28.

60. Quatman-Yates CC, Lee A, Hugentobler JA, Kurkowski BG, Myer GD, Riley MA. Test-retest consistency of a postural sway assessment protocol for adolescent athletes measured with a force plate. International Journal of Sports Physical Therapy. 2013 Dec;8(6)741-8.

61. Lempke LB, Howell DR, Eckner JT, Lynall RC. Examination of Reaction Time Deficits Following Concussion: A Systematic Review and Meta-analysis. Sports medicine (Auckland, NZ). 2020 Mar 11;1–19.

62. Eckner JT, Kutcher JS, Richardson JK. Effect of Concussion on Clinically Measured Reaction Time in 9 NCAA Division I Collegiate Athletes: A Preliminary Study. PM&R. 2011 Mar;3(3):212–8.

63. Eckner JT, Kutcher JS, Broglio SP, Richardson JK. Effect of sport-related concussion on clinically measured simple reaction time. British Journal of Sports Medicine. 2013 Dec 17;48(2):112–8.

64. Eckner JT, Kutcher JS, Richardson JK. Pilot Evaluation of a Novel Clinical Test of Reaction Time in National Collegiate Athletic Association Division I Football Players. Journal of Athletic Training. 2010 Jul;45(4):327–32.

65. Caccese JB, Eckner JT, Franco-MacKendrick L, Hazzard JB, Ni M, Broglio SP, et al. Clinical Reaction Time After Concussion: Change From Baseline Versus Normative-Based Cutoff Scores. Journal of Athletic Training. 2020 Dec 22;

66. Eckner JT, LIPPS DB, KIM H, Richardson JK, ASHTON-MILLER JA. Can a Clinical Test of Reaction Time Predict a Functional Head-Protective Response? Medicine & Science in Sports & Exercise. 2011 Mar;43(3):382–7.

67. Eckner JT, Kutcher JS, Richardson JK. Between-seasons test-retest reliability of clinically measured reaction time in National Collegiate Athletic Association Division I athletes. Journal of Athletic Training. 2011 Jul;46(4):409–14.

68. Nguyen CN, Clements RN, Porter LA, Clements NE, Gray MD, Baker RT. Examining Practice and Learning Effects with Serial Administration of the Clinical Reaction Time Test in Healthy Young Athletes. Journal of Sport Rehabilitation. 2018 Mar 27;1–22.

69. Echemendia RJ. Cerebral Concussion in Sport: An Overview. Journal of Clinical Sport Psychology, , , -. 2012 Oct 25;1–24.

70. Taylor K, Brooks BL, Schneider KJ, Blake TA, McKay CD, Meeuwisse WH, et al. Neurocognitive performance at return to play in elite youth hockey players with sport-related concussion. British Journal of Sports Medicine. 2014 Mar 11;48(7):664.1-664.

71. Russo CR, Lathan CE. An Evaluation of the Consistency and Reliability of the Defense Automated Neurocognitive Assessment Tool. Appl Psych Meas. 2015;39(7):566–72.

72. Lathan C, Spira JL, Bleiberg J, Vice J, Tsao JW. Defense Automated Neurobehavioral Assessment (DANA)—Psychometric Properties of a New Field-Deployable Neurocognitive Assessment Tool. Mil Med. 2013;178(4):365–71.

73. Haran FJ, Dretsch MN, Bleiberg J. Performance on the Defense Automated Neurobehavioral Assessment Across Controlled Environmental Conditions. Appl Neuropsychology Adult. 2016;23(6):1–7.

74. Pryweller JR, Baughman BC, Frasier SD, O'Conor EC, Pandhi A, Wang J, et al. Performance on the DANA Brief Cognitive Test Correlates With MACE Cognitive Score and May Be a New Tool to Diagnose Concussion. Front Neurol. 2020;11:839.

75. Nelson LD, Furger RE, Gikas P, Lerner EB, Barr WB, Hammeke TA, et al. Prospective, Head-to-Head Study of Three Computerized Neurocognitive Assessment Tools Part 2: Utility for Assessment of Mild Traumatic Brain Injury in Emergency Department Patients. Journal of the International Neuropsychological Society. 2017 Mar 27;23(04):293–303.

76. Servatius RJ, Spiegler KM, Handy JD, Pang KCH, Tsao JW, Mazzola CA. Neurocognitive and Fine Motor Deficits in Asymptomatic Adolescents during the Subacute Period after Concussion. J Neurotraum. 2018;35(8):1008–14.