Clinical Reaction-Time Performance Factors in Healthy Collegiate Athletes

Jaclyn B. Caccese, PhD*; James T. Eckner, MD, MS†; Lea Franco-MacKendrick, MS†; Joseph B. Hazzard, EdD, ATC‡; Meng Ni, PhD, PT§; Steven P. Broglio, PhD, ATC, FNATAAll; Thomas W. McAllister, MD¶; Michael McCrea, PhD, ABPP#; Thomas A. Buckley, EdD, ATC**

*School of Health and Rehabilitation Sciences, The Ohio State University, Columbus; †Department of Physical Medicine and Rehabilitation, University of Michigan, Ann Arbor; ‡Department of Exercise Science and §The Institute for Concussion Research & Services, Bloomberg University, Pennsylvania; AllMichigan Concussion Center, University of Michigan, Ann Arbor; ¶Department of Psychiatry, Indiana University School of Medicine, Indianapolis; #Department of Neurosurgery and Neurology, Medical College of Wisconsin, Milwaukee; **Department of Kinesiology and Applied Physiology and Biomechanics and Movement Science Interdisciplinary Program, University of Delaware, Newark

**Context:** In the absence of baseline testing, normative data may be used to interpret postconcussion scores on the clinical reaction-time test (RTclin). However, to provide normative data, we must understand the performance factors associated with baseline testing.

**Objective:** To explore performance factors associated with baseline RTclin from among candidate variables representing demographics, medical and concussion history, self-reported symptoms, sleep, and sport-related features.

**Design:** Cross-sectional study.

**Setting:** Clinical setting (eg, athletic training room).

**Patients or Other Participants:** A total of 2584 National Collegiate Athletic Association student-athletes (n = 1206 females [47%], 1377 males [53%], and 1 unreported (~0.1%); mass = 76.7 ± 18.7 kg; height = 176.7 ± 11.3 cm; age = 19.0 ± 1.3 years) from 3 institutions participated in this study as part of the Concussion Assessment, Research and Education Consortium.

**Main Outcome Measure(s):** Potential performance factors were sex; race; ethnicity; dominant hand; sport type; number of prior concussions; presence of anxiety, learning disability, attention-deficit disorder or attention-deficit/hyperactivity disorder, depression, or migraine headache; self-reported sleep the night before the test; mass; height; age; total number of symptoms; and total symptom burden at baseline. The primary study outcome measure was mean baseline RTclin.

**Results:** The overall RTclin was 202.0 ± 25.0 milliseconds. Female sex (parameter estimate [B] = 8.6 milliseconds, P < .001, Cohen d = 0.54 relative to male sex), black or African American race (B = 5.3 milliseconds, P = .001, Cohen d = 0.08 relative to white race), and limited-contact (B = 4.2 milliseconds, P < .001, Cohen d = 0.30 relative to contact) or noncontact (B = 5.9 milliseconds, P < .001, Cohen d = 0.38 relative to contact) sport participation were associated with slower RTclin. Being taller was associated with a faster RTclin, although this association was weak (B = −0.7 milliseconds, P < .001). No other predictors were significant. When adjustments are made for sex and sport type, the following normative data may be considered (mean ± standard deviation): female, noncontact (211.5 ± 25.8 milliseconds), limited contact (212.1 ± 24.3 milliseconds), contact (203.7 ± 21.5 milliseconds); male, noncontact (199.4 ± 26.7 milliseconds), limited contact (196.3 ± 23.9 milliseconds), contact (195.0 ± 23.8 milliseconds).

**Conclusions:** Potentially clinically relevant differences existed in RTclin for sex and sport type. These results provide normative data adjusting for these performance factors.

**Key Words:** concussion, mild traumatic brain injury, sex, sport type

| Key Points |
| --- |
| • Performance factors associated with baseline clinical reaction time were sex, race, sport type, and height. |
| • Both sex and sport type represented clinically relevant differences in clinical reaction time. |
| • When adjustments are made for sex and sport type, the following normative data may be considered (mean ± standard deviation): female, noncontact (211.5 ± 25.8 milliseconds), limited contact (212.1 ± 24.3 milliseconds), contact (203.7 ± 21.5 milliseconds); male, noncontact (199.4 ± 26.7 milliseconds), limited contact (196.3 ± 23.9 milliseconds), contact (195.0 ± 23.8 milliseconds). |

Between 1.6 million and 3.8 million sport-related concussions (SRCs) occur annually in the United States. The symptom presentation of sport-related concussion symptoms is highly variable, so a multifaceted and multimodal assessment that supports the clinical examination is the recommended approach for diagnosing SRC and tracking recovery. This assessment may include tests of mental status and cognition, ocular motor function,
gross sensorimotor function, coordination, gait, vestibular function, balance, and reaction time (RT). According to the 5th “Consensus Statement on Concussion in Sport,” baseline testing may be useful but is not necessary for interpreting postinjury scores. In the absence of baseline testing, normative data are used to interpret postinjury scores. For neurocognitive assessments (eg, Immediate Post-Concussion Assessment and Cognitive Testing [Impact]), clinical neuropsychologists use demographically adjusted normative data to interpret postinjury scores. For other assessments (eg, RT), performance factors, such as demographics, medical and concussion history, self-reported symptoms, sleep, and sport-related features, have not been assessed. Without a comprehensive assessment of these performance factors, it is difficult to provide normative data that will aid in interpreting postinjury scores in the absence of baseline testing.

The measurement of RT typically relies on specialized computer programs as part of the neurocognitive evaluation, which limits its accessibility and translatability in many athletic settings. To enable all health care practitioners to assess simple RT, Eckner et al developed a clinically feasible test of simple RT (Rtclin), which involved timing how long it took participants to catch a suspended vertical dowel by pinch grip. Clinical RT scores were moderately reliable (intraclass correlation coefficient = 0.645 over a 1-year test-retest interval), valid (R = 0.445 compared with computerized RT testing, R = 0.725 compared with a functional head-protection task), and sensitive (75%) and specific (68%) in SRC recognition. However, performance factors associated with Rtclin have received limited attention in the literature. Understanding the performance factors associated with Rtclin will allow us to provide normative data that can be used in the absence of baseline testing.

Immediate Post-Concussion Assessment and Cognitive Testing (Impact Applications, Inc, Coralville, IA) is the most widely used computerized neurocognitive assessment in SRC management and includes RT tests resulting in an RT composite score. Performance factors influencing Impact RT composite scores in National Collegiate Athletic Association (NCAA) student-athletes include sex, sport type (ie, contact, limited contact, noncontact), and neurodevelopmental and concussion history, although the literature is mixed. Composite Impact scores may differ from Rtclin performance as a result of different experimental setups and stimuli. Therefore, the purpose of our study was to explore the effects of performance factors, including demographics (eg, sex), medical (eg, neurodevelopmental) and concussion history, self-reported symptoms, sleep, and sport-related features (eg, level of contact), on baseline Rtclin performance. Based on computerized RT performance factors in NCAA student-athletes, we hypothesized that contact-sport athletes and those with neurodevelopmental disorders would have slower Rtclin but that no differences based on demographic variables or concussion history would be present.

METHODS

Participants

This study was part of the NCAA-Department of Defense Concussion Assessment, Research and Education (CARE) Consortium, a large-scale, multisite study of the natural history of concussion in both sexes and multiple sports. All CARE study participants undergo the Level A assessment battery, which includes demographics and medical history, neurocognitive assessment, neurologic status, postural stability, and symptom evaluation. Selected instruments from the Level B assessments (ie, emerging assessments) are added at the discretion of each performance site. Data from athletes enrolled at all 3 performance sites that elected to use Rtclin as part of the Level B assessments were included in the analyses (N = 4782). Because some athletes participated in the CARE Consortium study during more than 1 season, only the first season’s baseline results were analyzed (n = 3297). Potential participants were excluded if they did not complete a baseline Rtclin assessment (n = 90) or if they were tested with a Rtclin protocol consisting of < 8 data trials (n = 623). Therefore, 2584 participants were included in the final primary analysis (n = 1206 females [47%], n = 1377 males [53%], n = 1 unreported (< 0.1%); mass = 76.7 ± 18.7 kg; height = 176.7 ± 11.3 cm; age = 19.0 ± 1.3 years; Sport Concussion Assessment Tool [SCAT] total symptom score = 2.2 ± 3.3; SCAT symptom severity score = 3.8 ± 7.1). All study procedures were reviewed by the University of Michigan Institutional Review Board and the US Army Medical Research and Materiel Command Human Research Protection Office, as well as the local institutional review board at each performance site. Participants provided written informed consent before the study began.

Clinical RT Testing

The Rtclin was performed as previously described (Figure 1). Briefly, participants were instructed to catch an 80-cm wooden dowel coated in high-friction tape and marked in 0.5-cm increments as quickly as possible. The dowel was embedded in a weighted rubber disk of diameter = 7.5 cm, height = 2.5 cm, and mass = 256 g. The participant sat with the dominant hand positioned at
the edge of the table in an open C-shape position. The examiner initially held the dowel so that the weighted rubber disk was in line with the participant’s first and second digits and then released the dowel at predetermined randomly assigned time intervals ranging from 2 to 5 seconds.7–10,12,13,19,20 The participant caught the dowel as quickly as possible. The distance the apparatus fell was determined from the marked increments on the dowel. The $RT_{\text{clin}}$ values were calculated by converting distance to time, in milliseconds, using the formula for a body falling under the influence of gravity ($D = 1/2 \ g t^2$). Two practice trials were followed by 8 data-collection trials. If a participant did not catch the dowel, then the examiner recorded the “dropped” trial and the participant continued with the next trial; dropped trials were not replaced. Mean $RT_{\text{clin}}$ was then calculated for participants from all successfully completed trials.7–10,12,13,19,20

**Statistical Analyses**

Generalized linear modeling was used to establish performance factors that might be associated with $RT_{\text{clin}}$. Potential performance factors (self-reported) were entered in the following order: sex (male, female)17; race (American Indian or Alaska Native, Asian, black or African American, Native Hawaiian or other Pacific Islander, white, multiple races, unknown or not reported)21; ethnicity (Hispanic or Latino, not Hispanic or Latino, unknown or not reported)21; dominant hand (right, left, ambidextrous)22; sport type (contact, limited contact, noncontact)4; number of prior concussions, including both diagnosed and undiagnosed (0, 1–2, >3)16; presence of anxiety (yes, no)23; learning disability (yes, no)18,23; attention-deficit disorder or attention-deficit/ hyperactivity disorder (yes, no)18,23; depression (yes, no)23; migraine headache (yes, no)23; self-reported sleep the night before the test (<7, 7–9, >9 hours, not reported) as self-reported on the ImPACT24; mass (continuous)25; height (continuous)23; age (continuous)22; total number of SCAT-3 symptoms (continuous)26; total SCAT-3 symptom burden (weighted score on the graded symptom checklist, continuous).26 We fit the generalized linear model for $RT_{\text{clin}}$ based on a normal (Gaussian) distribution (Figure 2). Significance was defined a priori as $P < .05$. This analysis was conducted using SPSS (version 24; IBM Corp, Armonk, NY). Effect sizes are included to illustrate the clinical meaningfulness of the findings.

**RESULTS**

The overall $RT_{\text{clin}}$ was 202.0 ± 25.0 milliseconds, with a breakdown by subgroup provided in Table 1. The generalized linear model was a suitable fit to the data (omnibus test: likelihood ratio $\chi^2 = 256.496, P < .001$). In this model, sex, race, sport type, and height were the only significant predictors of $RT_{\text{clin}}$ (Table 2). Female sex ($B = 8.6$ milliseconds, $P < .001$, Cohen $d = 0.54$ relative to male sex), black or African American race ($B = 5.3$ milliseconds, $P = .001$, Cohen $d = 0.08$ relative to white race), and limited-contact ($B = 4.2$ milliseconds, $P < .001$, Cohen $d = 0.30$ relative to contact) and noncontact ($B = 5.9$ milliseconds, $P < .001$, Cohen $d = 0.38$ relative to contact) sport participation were associated with slower $RT_{\text{clin}}$ when all other factors were controlled (Table 1). Being taller was associated with a faster $RT_{\text{clin}}$, although this association was weak ($B = 8.6$ milliseconds, $P < .001$; Table 2). No other predictors were significant (Table 2). When adjustments are made for sex and sport type, the following normative data may be considered (mean ± standard deviation): female, noncontact (211.5 ± 25.8 milliseconds), limited contact (212.1 ± 24.3 milliseconds), contact (203.7 ± 21.5 milliseconds); male, noncontact (199.4 ± 26.7 milliseconds), limited contact (196.3 ± 23.9 milliseconds), contact (195.0 ± 23.8 milliseconds; Table 3).

**DISCUSSION**

Several performance factors may be associated with $RT_{\text{clin}}$ in NCAA student-athletes, and adjustments should be made for these performance factors when providing normative baseline data. The purpose of our study was to explore the effects of performance factors, including demographics (eg, sex), medical (eg, neurodevelopmental) and concussion history, self-reported symptoms, sleep, and sport-related features (eg, level of contact), on baseline $RT_{\text{clin}}$ performance. Female sex, black or African American race, limited-contact or noncontact-sport participation, and being shorter were associated with slower $RT_{\text{clin}}$. After evaluating effect sizes, we suggest that female sex ($Cohend = 0.54$ relative to male sex) and sport type (limited contact: $Cohend = 0.30$ relative to contact; noncontact: $Cohend = 0.38$ relative to contact) result in potentially clinically relevant differences. We therefore have provided normative data based on these 2 performance factors, which can be considered in the absence of baseline testing.

Sex and sport-contact type were associated with $RT_{\text{clin}}$, whereby males (196 ± 24 milliseconds) had faster $RT_{\text{clin}}$ than females (209 ± 24 milliseconds, $B = 8.6$ milliseconds,
Cohen $d = 0.54$) and contact-sport participants (197 ± 23 milliseconds) had faster $RT_{clin}$ than both limited-contact (205 ± 25 milliseconds, $B = 4.2$ milliseconds, Cohen $d = 0.30$) and noncontact (207 ± 27 milliseconds, $B = 5.9$ milliseconds, Cohen $d = 0.38$) participants. Although these findings differ from those for computerized RT testing,4,17 $RT_{clin}$ is strongly correlated with a task designed to simulate a natural head-protective response in a sport-related environment and may be a better indicator of functional RT.19 Males and contact-sport participants may perform better on functional RT testing as a result of faster processing speed and muscle composition, or contact-sport participants may elect to participate in these sports because they have faster RT.

Although statistically, participants of black or African American race (204 ± 27 milliseconds, $B = 5.3$ milliseconds, Cohen $d = 0.08$ relative to white race) had slower $RT_{clin}$, these differences were small and may be clinically insignificant. We aimed to identify common performance factors in $RT_{clin}$ that were consistent with previous RT and neurocognitive assessments, but some performance factors (eg, race) had categories with low frequencies (ie, 80% of all participants were white). This is a limitation, though these data likely represent the NCAA
athletic population. Considering that only 11.7% of our population reported being African American, these findings may be a result of the small sample size and should be investigated further in the future.

Many factors have been associated with RT in previous work. Age is typically associated with RT. Specifically, RT decreases from infancy into the late 20s and then begins to slow.27 Considering that the age range of our participants was 17 to 28 years, our sample may have lacked enough variation in age to show this relationship. Similarly, RT increases with fatigue; however, 1 group28 induced fatigue with 24+ hours of sleep deprivation, and our participants averaged 6.9 ± 1.5 hours of sleep the night before the test. Moreover, fatigue is multifaceted, and as such, we cannot say that the number of hours of sleep reported the night before the test was a measure of fatigue. Although we were able to evaluate a number of potential performance factors, additional factors such as arousal, fasting, alcohol consumption, effort and motivation, personality type, exercise, stimulant medications, and intelligence should be considered in future research.

According to the 5th “Consensus Statement on Concussion in Sport,” baseline testing may be useful but is not necessary to interpret neurocognitive performance after SRC. We have provided normative data adjusting for sex and contact-sport type that can be used in interpreting postinjury scores in the absence of baseline testing. Previous authors12,13 suggested that a 0-millisecond cutoff score compared with each athlete’s own baseline score during the preseason maximized the sensitivity and specificity of SRC diagnosis, so these normative data must be tested with regard to postinjury scores to determine their sensitivity and specificity for SRC management. Therefore, future investigators should determine whether clinicians may consider using these normative data in lieu of individualized baseline measures.

Although we identified several significant performance factors for $RT_{\text{clin}}$ and provided normative data for interpreting postinjury scores in the absence of baseline testing, our study had several limitations. Some participants ($n = 53$) had a $RT_{\text{clin}} < 150$ milliseconds, which is physiologically unlikely,29,30 considering that the stimulus-detection time alone is approximately 120 milliseconds, or the latency of early cortical components of the visual-evoked potentials.22 These unusually fast $RT_{\text{clin}}$ times suggest that participants were likely able to anticipate the apparatus drop. However, they were not statistical outliers, and such an $RT_{\text{clin}}$ may occur in the context of typical baseline testing, so these individuals’ data were not removed from analyses. To minimize the likelihood of anticipation, examiners were instructed to drop the apparatus at randomly assigned time intervals ranging from 2 to 5 seconds, but some participants may still have been able to predict timing of the drop. Additionally, an athlete’s motivation may influence baseline $RT_{\text{clin}}$, though previous research suggested that athletes appeared to be more motivated during $RT_{\text{clin}}$ testing than during computerized RT testing.20 It is certainly possible that an athlete might purposely perform poorly (ie, sandbagging) at preseason baseline testing in an attempt to mask deficits after a suspected concussion. Finally, we recruited only NCAA student-athletes, and thus, these findings may not be applicable to other populations.

Our aim was to explore factors associated with baseline $RT_{\text{clin}}$ performance and to provide normative data based on these performance factors. We saw potentially clinically relevant differences in $RT_{\text{clin}}$ for sex and contact-sport type, whereby females and noncontact and limited-contact athletes had slower $RT_{\text{clin}}$ performance. When adjustments are made for sex and sport type, the following normative data may be considered (mean ± standard deviation): female, noncontact (211.5 ± 25.8 milliseconds), limited

### Table 2. Test of Model Effects for Generalized Linear Model

| Source                                    | Wald $\chi^2$ | df | Significance | B     | Standard Error |
|-------------------------------------------|---------------|----|--------------|-------|----------------|
| (Intercept)                               | 319.303       | 1  | <.001        | 250.536 | 15.547         |
| Sex                                       | 40.075        | 1  | <.001b       | -4.470 | 11.007         |
| Race                                      | 16.194        | 6  | .019b        | 2.862  | 2.964          |
| Ethnicity                                 | 1.063         | 2  | .588         | -1.00  | 1.00           |
| Dominant hand                             | 3.304         | 2  | .192         | -1.00  | 1.00           |
| Sport                                     | 22.665        | 2  | <.001b       | 3.76  | 3.76           |
| Previous concussion                       | 2.629         | 2  | .269         | -1.00  | 1.00           |
| Anxiety                                   | 2.190         | 1  | .139         | -1.00  | 1.00           |
| Learning disability                       | 0.350         | 1  | .554         | -1.00  | 1.00           |
| Attention-deficit disorder or             |               |    |              |       |                |
| attention-deficit/hyperactivity disorder  | 0.146         | 1  | .702         | -1.00  | 1.00           |
| Depression                                | 0.803         | 1  | .370         | -1.00  | 1.00           |
| Migraine                                  | 1.083         | 1  | .298         | -1.00  | 1.00           |
| Sleep                                     | 2.973         | 3  | .396         | -1.00  | 1.00           |
| Weight                                    | 0.609         | 1  | .435         | -1.00  | 1.00           |
| Height                                    | 13.192        | 1  | <.001b       | 1.00   | 1.00           |
| Age                                       | 1.608         | 1  | .205         | -1.00  | 1.00           |
| SCAT Total Symptom Score                  | 0.027         | 1  | .870         | -1.00  | 1.00           |
| SCAT –3 Symptom Severity Score            | 0.041         | 1  | .840         | -1.00  | 1.00           |

Abbreviation: B, parameter estimate; SCAT, Sport Concussion Assessment Tool.

* Parameter estimates from the generalized linear model are also provided.

* Significant predictor.
Table 3. Clinical Reaction-Time Test: Normative Data by Sex and Sport Type

| Time, milliseconds | Sex    | Sport Type | n  | Mean ± SD | Error | 95% Confidence Interval | Above-Average Score Range | Broadly Normal Score Range | Below-Average Score Range | Very Poor Score Range |
|-------------------|--------|------------|----|-----------|-------|-------------------------|--------------------------|---------------------------|--------------------------|------------------------|
| 606               | Women  | Noncontact | 340| 211.5 ± 26.8 | 6      | 209.0, 214.1, 216.9      | 189.9–220.4              | 173.2–210.9              | 157.6–194.8              | 128.8–166.0              |
| 606               | Women  | Limited contact | 424| 203.7 ± 24.3 | 6      | 201.4, 206.0, 210.6      | 189.9–220.4              | 173.2–210.9              | 157.6–194.8              | 128.8–166.0              |
| 606               | Men    | Noncontact | 171| 199.4 ± 26.7 | 6      | 195.8, 203.0, 213.6      | 189.9–220.4              | 173.2–210.9              | 157.6–194.8              | 128.8–166.0              |
| 606               | Men    | Limited contact | 859| 195.0 ± 23.8 | 6      | 193.4, 196.6, 201.8      | 189.9–220.4              | 173.2–210.9              | 157.6–194.8              | 128.8–166.0              |

- Above-average scores occurred in ~15% of the normative sample. This classification range corresponds to the 85th percentile.
- Broadly normal scores occurred in ~60% of the normative sample. This classification range corresponds to the 25th to 84th percentile.
- Below-average scores occurred in ~15% of the normative sample. This classification range corresponds to the 25th to 84th percentile.
- Poor scores occurred in ~8% of the normative sample. This classification range corresponds to the 2nd to 9th percentile.
- Very poor scores occurred in fewer than 2% of the normative sample. This classification range corresponds to the 2nd percentile.

Contact (212.1 ± 24.3 milliseconds), contact (203.7 ± 21.5 milliseconds); male, noncontact (199.4 ± 26.7 milliseconds), limited contact (196.3 ± 23.9 milliseconds), contact (195.0 ± 23.8 milliseconds).

ACKNOWLEDGMENTS

This study was supported in part by the Grand Alliance CARE Consortium, funded by the National Collegiate Athletic Association and the US Department of Defense. The US Army Medical Research Acquisition Activity, Fort Detrick, Maryland, is the awarding and administering acquisition office. This study was supported by the Office of the Assistant Secretary of Defense for Health Affairs through the Psychological Health and Traumatic Brain Injury Program under award W81XWH-14-2-D151. Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the US Department of Defense (Defense Health Program funds).

REFERENCES

1. Langlois JA, Rutland-Brown W, Wald MM. The epidemiology and impact of traumatic brain injury: a brief overview. J Head Trauma Rehabil. 2006;21(5):375–378.
2. McCrory P, Meeuwisse W, Dvorak J, et al. Consensus statement on concussion in sport—the 5th International Conference on Concussion in Sport held in Berlin, October 2016. Br J Sports Med. 2017;51(11):838–847.
3. Broglio SP, McCrea M, McAllister T, et al. A national study on the effects of concussion in collegiate athletes and US military service academy members: the NCAA–DoD Concussion Assessment, Research and Education (CARE) Consortium structure and methods. Sports Med. 2017;47(7):1437–1451.
4. Katz BP, Kudela M, Harezlak J, et al. Baseline performance of NCAA athletes on a concussion assessment battery: a report from the CARE Consortium. Sports Med. 2018;48(8):1971–1985.
5. Echemendia RJ, Bruce JM, Bailey CM, Sanders JF, Arnett P, Vargas G. The utility of post-concussion neuropsychological data in identifying cognitive change following sports-related MTBI in the absence of baseline data. Clin Neuropsychol. 2012;26(7):1077–1091.
6. Heaton RK, Ryan L, Grant I. Demographic influences and use of demographically corrected norms in neuropsychological assessment. In: Grant I, Adams KM, eds. Neuropsychological Assessment of Neuropsychiatric and Neurological Disorders. New York, NY: Oxford University Press; 2009:127–155.
7. Eckner JT, Whittacre RD, Kirsch NL, Richardson JK. Evaluating a clinical measure of reaction time: an observational study. Percept Mot Skills. 2009;108(3):717–720.
8. 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. J Athl Train. 2010;45(4):327–332.
9. Eckner JT, Kutcher JS, Richardson JK. Between-seasons test-retest reliability of clinically measured reaction time in National Collegiate Athletic Association Division I athletes. J Athl Train. 2011;46(4):409–414.
10. Eckner JT, Richardson JK, Kim H, Joshi MS, Oh YK, Ashton-Miller JA. Reliability and criterion validity of a novel clinical test of simple and complex reaction time in athletes. Percept Mot Skills. 2015;120(3):841–859.
11. Broglio SP, Katz BP, Zhao S, McCrea M, McAllister T; CARE Consortium Investigators. Test-retest reliability and interpretation of common concussion assessment tools: findings from the NCAA-DoD CARE Consortium. Sports Med. 2018;48(5):1255–1268.
12. 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;3(3):212–218.

13. Eckner JT, Kutcher JS, Broglio SP, Richardson JK. Effect of sport-related concussion on clinically measured simple reaction time. *Br J Sports Med*. 2014;48(2):112–118.

14. Buckley TA, Burdette G, Kelly K. Concussion-management practice patterns of National Collegiate Athletic Association Division II and III athletic trainers: how the other half lives. *J Athl Train*. 2015;50(8):879–888.

15. Kelly KC, Jordan EM, Joyner AB, Burdette GT, Buckley TA. National Collegiate Athletic Association Division I athletic trainers’ concussion-management practice patterns. *J Athl Train*. 2014;49(5):665–673.

16. Broglio SP, Ferrara MS, Piland SG, Anderson RB, Collie A. Concussion history is not a predictor of computerised neurocognitive performance. *Br J Sports Med*. 2006;40(9):802–805.

17. Covassin T, Swanik CB, Sachs M, et al. Sex differences in baseline neuropsychological function and concussion symptoms of collegiate athletes. *Br J Sports Med*. 2006;40(11):923–927.

18. Elbin RJ, Kontos AP, Kegel N, Johnson E, Burkhart S, Schatz P. Individual and combined effects of LD and ADHD on computerized neurocognitive concussion test performance: evidence for separate norms. *Arch Clin Neuropsych*. 2013;28(5):476–484.

19. Eckner JT, Lipp DB, Kim H, Richardson JK, Ashton-Miller JA. Can a clinical test of reaction time predict a functional head-protective response? *Med Sci Sports Exerc*. 2011;43(3):382–387.

20. Eckner JT, Chandran S, Richardson JK. Investigating the role of feedback and motivation in clinical reaction time assessment. *PM R*. 2011;3(12):1092–1097.

21. Houck Z, Asken B, Clugston J, Perlstein W, Bauer R. Socioeconomic status and race outperform concussion history and sport participation in predicting collegiate athlete baseline neurocognitive scores. *J Int Neuropsychol Soc*. 2018;24(1):1–10.

22. Woods DL, Wyma JM, Yund EW, Herron TJ, Reed B. Factors influencing the latency of simple reaction time. *Front Hum Neurosci*. 2015;9:131.

23. Cottle JE, Hall EE, Patel K, Barnes KP, Ketcham CJ. Concussion baseline testing: pre-existing factors, symptoms, and neurocognitive performance. *J Athl Train*. 2017;52(2):77–81.

24. McChure DJ, Zuckerman SL, Kutscher SJ, Gregory AJ, Solomon GS. Baseline neurocognitive testing in sports-related concussions: the importance of a prior night’s sleep. *Am J Sports Med*. 2014;42(2):472–478.

25. Nikam LH, Gadkari JV. Effect of age, gender and body mass index on visual and auditory reaction times in Indian population. *Indian J Physiol Pharmacol*. 2012;56(1):1–10.

26. Bailey CM, Samples HL, Broshek DK, Freeman JR, Barth JT. The relationship between psychological distress and baseline sports-related concussion testing. *Clin J Sport Med*. 2010;20(4):272–277.

27. Der G, Deary IJ. Age and sex differences in reaction time in adulthood: results from the United Kingdom Health and Lifestyle Survey. *Psychol Aging*. 2006;21(1):62–73.

28. van den Berg J, Neely G. Performance on a simple reaction time task while sleep deprived. *Percept Mot Skills*. 2006;102(2):589–599.

29. Magill RA, Anderson DI. *Motor Learning and Control: Concepts and Applications*. New York, NY: McGraw-Hill; 2007.

30. Zelaznik HN. *Advances in Motor Learning and Control*. Champaign, IL: Human Kinetics; 1996.

Address correspondence to Thomas A. Buckley, EdD, ATC, University of Delaware, 349 The Tower at STAR, 100 Discovery Boulevard, Newark, DE 19713. Address e-mail to tbuckley@udel.edu.