Journal of Athletic Training 2017;52(1):51–57
doi: 10.4085/1062-6050-51.12.27

www.natajournals.org

original research

Baseline Neurocognitive Performance and Clearance for Athletes to Return to Contact

Breton M. Asken, MS, ATC*; James R. Clugston, MD, CAQSM†; Aliyah R. Snyder, MS*; Russell M. Bauer, PhD, ABPP/CN*

*Department of Clinical and Health Psychology and †University Athletic Association and Department of Community Health and Family Medicine, University of Florida, Gainesville

Context: Computerized neurocognitive assessments are commonly used to manage sport-related concussion. Variations in baseline performance may influence neurocognitive performance after injury as well as the amount of time needed for an athlete to be cleared for return to sport participation.

Objective: To investigate the relationship between mean baseline Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) scores and postconcussion reliable decline as well as the association between postconcussion cognitive decline and days missed after injury.

Design: Cross-sectional study.

Setting: University concussion databank.

Patients or Other Participants: A total of 84 collegiate athletes who sustained a concussion between 2008 and 2015 were studied. For each ImPACT composite score (verbal memory, visual memory, visual motor speed, reaction time), athletes were grouped based on the presence or absence of reliable decline and on the presence of reliable decline in 0, 1, 2, 3, or 4 cognitive domains.

Main Outcome Measure(s): Outcome measures were baseline ImPACT composite scores and days missed due to concussion.

Results: Athletes with a reliable decline in visual memory scored higher on baseline visual memory than did athletes with no decline or an improvement ($t_{82} = -2.348$, $P = .021$, $d = 0.65$). When comparing athletes who displayed a reliable decline with those who showed no change or an improvement in any composite score, days missed did not differ. The number of composite scores with a reliable decline demonstrated no main effect on days missed ($P = .530$).

Conclusions: Athletes who exhibited cognitive decline in most or all of the composite scores did not miss more days after injury than athletes with a decline in fewer or none of the composite scores. Athletes should be educated regarding the lack of association between baseline neurocognitive scores and the presence or absence of a reliable decline after concussion, as well as the fact that, on average, individuals with a reliable decline across multiple domains did not miss more time after concussion.

Key Words: brain injuries, computerized testing, ImPACT, collegiate athletes

Key Points

- Athletes who demonstrated a reliable postconcussion decline on the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) performed better in only the visual memory domain at baseline.
- The presence or absence of a reliable decline on any ImPACT composite score after concussion was not associated with days lost from sport.
- After concussion, athletes with a reliable decline on most or all ImPACT composite scores missed no more time than those with fewer or no declines.

Neurocognitive evaluations have been an integral piece of concussion management for almost 3 decades.[1–3] In particular, computerized assessments have become widely used[4] and are broadly known as computerized neurocognitive assessment devices or computerized neurocognitive tests (CNTs).[5] The idea that CNTs provide incremental data that improve the health and safety of athletes has been controversial.[6,7] Proponents argue that CNTs offer advantages over symptom reports by supplying objective measurements of cognition after concussion; others question their true objectivity because of a reliance on individual effort.

The Immediate Post-Concussion Assessment and Cognitive Test (ImPACT; ImPACT Applications Inc, Pittsburgh, PA) is one of the most commonly used CNTs. This instrument uses 6 subtest modules to produce 4 composite scores: verbal memory, visual memory, visual motor speed (or processing speed), and reaction time. After a 1-week test-retest interval, Iverson et al[8] reported Pearson correlations of 0.70, 0.67, 0.86, and 0.79 for the 4 composite scores, respectively. Using intraclass correlation coefficients (ICCs) to assess 1-year test-retest reliability, Elbin et al[9] reported ICCs of 0.62, 0.70, 0.85, and 0.76, respectively. Schatz[10] investigated ImPACT reliability over a 2-year span and found degradation of these values, reporting ICCs of 0.46, 0.65, 0.74, and 0.68 for verbal memory, visual memory, visual motor speed, and reaction time, respectively. In both baseline and postconcussion settings,[1,11,12] ImPACT has been validated against other neuropsychological measures and was shown to be approximately 90% sensitive and 70% specific in detecting cognitive dysfunction and diagnosing concussion,[3,13] even in the absence of reported symptoms.[13,14] However, other investigators have shown poor to moderate reliability,[6,15] low sensitivity,[6] and a high (30%) false-positive rate.[3]

To determine if meaningful performance differences occurred postconcussion, ImPACT uses established reliable change criteria. Statistically, reliable change indices estimate the probability that a difference score was not simply the result of measurement error and also account for potential practice effects.[16,17] Clinically, reliable change criteria are used to increase the confidence that a decline in performance represents a true deficit rather than normal performance variability with repeat assessments. Applying the criteria determined by Iverson et al,[8] ImPACT provides clinicians with clear indicators of whether or not an athlete is exhibiting performance deficits beyond the reliable change cutoff for each composite score. Yet because Iverson et al[8] used a 1-week test-retest design, the calculated reliable change indices may not be as appropriate for an athlete whose baseline test was performed months or years before a concussion and subsequent testing. As such, the frequency with which baseline assessments should be performed is debated.[9,10]

Similar to most neurocognitive tests, demographic and environmental factors can influence performance on ImPACT and other CNTs. Sex, age, test environment, mood disorder, and developmental disorders (eg, attention-deficit/hyperactivity disorder [ADHD], learning disability [LD], dyslexia) affect performance. Females outperform males on tests of verbal memory, whereas males outperform females on tests of visual memory.[18,19] Within the relatively limited age range studied, performance appeared to improve with age.[18–20] Testing individuals in a group setting can lead to worse test scores,[20–22] and the presence of mood or developmental disorders is also associated with worse performance.[23–25]

Baseline scores are purportedly useful as a within-individual comparison standard when an athlete sustains a concussion; postinjury results are compared with baseline scores to determine whether and when the athlete is "back to normal." However, baseline testing is potentially vulnerable to the effects of variable efforts[26] and purposeful poor performance, also known as malingering or "sandbagging." Bailey et al[27] demonstrated that athletes with "suspect motivation" on traditional neuropsychological test measures at baseline showed disproportionate performance improvement 1 week after injury compared with "high-motivation" athletes at baseline. Anecdotal evidence suggests that athletes may attempt to generate a low baseline score in order to regain their preinjury baseline performance level more easily after a concussion and ultimately be cleared to return to play (RTP) more quickly.[28,29] To date, no investigators have examined differences in time to clearance for athletic participation based on mean baseline neurocognitive performance or the degree of reliable cognitive decline after concussion.

Culturally, this approach is associated with a de-emphasis on concussion concerns, consistent with previous research that identified high rates of concussion underreporting[30,31] as well as minimization of symptoms after concussion.[32] Attributing worse-than-expected performance to suboptimal effort versus purposeful malingering is a challenge, and as such, many authors have had to rely on predetermined cutoff scores to identify potential instances without being able to definitively say the reason for low scores. From 6% to 11% of baseline scores may reflect poor effort or malingering.[10,22,33] Despite evidence that baseline assessments are susceptible to effort effects, other studies[34,35] showed that successfully sandbagging (ie, purposely performing poorly but still achieving a valid test score) on CNTs is difficult to accomplish. Considering the cultural belief that some athletes may attempt to obtain low baseline scores, it is worth investigating whether baseline scores are actually associated with elapsed time between concussion and RTP.

The purpose of our study was to evaluate mean baseline CNT performance between those with and those without postconcussion reliable decline and to examine mean differences in days missed after a concussion based on the number of domains in which an individual exhibited a reliable decline. We first assessed baseline performance differences between athletes who did and those who did not exhibit reliable declines postconcussion for each ImPACT composite score and hypothesized that athletes exhibiting a statistically reliable decline after concussion would have higher baseline scores than athletes who exhibited no change or an improvement after concussion, possibly reflecting the statistical properties of the test (ie, floor effects). We then investigated whether athletes exhibiting cognitive decline in a greater number of domains would, on average, lose more time from athletic activity and hypothesized that no such relationship would exist. Concussion management is multifaceted, and clinical decision making often reflects a variety of considerations at the individual level. If our hypotheses are correct, communicating such results in educational concussion-management programs has the potential to more accurately inform athletes about neurocognitive baseline testing. After a concussion, athletes may benefit from the understanding that broad cognitive deficits (ie, reliable declines in multiple domains) do not necessarily indicate they will have a longer recovery time.

METHODS

The University of Florida Concussion Databank (UFCD) contains concussion-related medical records for all consenting varsity athletes. With approval from the university institutional review board, we accessed the UFCD to obtain records for all University of Florida athletes who sustained a concussion between 2008 and 2015. For the present study, a *concussion* was defined as a brain injury diagnosed by a team physician or certified athletic trainer (or both). Our primary outcome variable, *days missed*, was defined as the number of days elapsed between the date of concussion and the date the athlete was cleared by a team physician to participate in contact activities. Both the concussion definition and the clearance guidelines for RTP were in accordance with the university's concussion-management protocol, which emulates the recommendations of the International Conferences on Concussion in Sport's consensus statements.[36,37] Our definition of clearance to RTP coincides with approval to begin step 5 of the graduated RTP protocol. This step represents the terminal step in the RTP process for noncollision-sport athletes and approval for a return to contact participation for collision-sport athletes. Although the definition of concussion and the

Table 1. Criteria for Reliable Decline From Baseline for ImPACT Composite Scores (Derived From Iverson et al[8])

Composite Score	Reliable Decline Criteria Based on 80% Confidence Interval
Verbal memory, points	9
Visual memory, points	14
Visual motor speed, points	3
Reaction time, s	0.06

Abbreviation: ImPACT, Immediate Post-Concussion Assessment and Cognitive Test (ImPACT Applications, Inc, Pittsburgh, PA).

clearance guidelines remained relatively consistent over the years encompassed within this analysis, we nonetheless evaluated the potential effect of changing treatment standards over time and found no correlation between year of injury and days missed ($P = .471$).

Computerized Neurocognitive Testing

University of Florida varsity athletes completed the online version of ImPACT at baseline and after a concussion under the supervision of a certified athletic trainer in accordance with the university's concussion-management protocol. Composite scores are obtained in 4 areas of cognitive functioning: verbal memory, visual memory, visual motor speed, and reaction time. For a detailed description of ImPACT composite scores and individual test modules, please refer to the ImPACT manual.[38]

Postconcussion cognitive decline was defined as a statistically reliable performance decline relative to baseline. Reliable change statistics were based on previous psychometric analyses of ImPACT's test-retest reliability in high school and collegiate athletes (Table 1).[8] Athletes were placed in 1 of 2 groups for each ImPACT composite score: (1) those who showed a reliable decline relative to baseline or (2) those who showed no change or a reliable improvement. Athletes were also grouped by the number of composite scores in which they exhibited a reliable decline (0, 1, 2, 3, or 4).

Exclusion Criteria

Athletes were excluded if their baseline ImPACT performance was considered invalid based on the validity indicators described in the ImPACT manual.[38] These criteria are (1) >30 incorrect responses on the X's and O's test module, (2) impulse control composite score >30, (3) <69% correct on word memory learning, (4) <50% correct on design memory learning, or (5) <8 correct on the 3 letters test module.

Athletes were also excluded if any of the following information was missing from the UFCD: baseline ImPACT test scores before the date of injury, date of concussion, postconcussion ImPACT test scores, or date of clearance for RTP.

A total of 84 athletes met the inclusion criteria for this study (mean age at baseline = 18.9 ± 0.7 years, mean age when injured = 20.4 ± 1.3 years), and 29 were excluded. Sample characteristics are described in Table 2. Athletes in this study participated in the following sports: football (55), women's lacrosse (7), women's soccer (4), men's basketball (3), men's swimming and diving (3), women's basketball (3), women's volleyball (3), women's swimming and diving (2), women's track and field (2), men's tennis (1), and women's gymnastics (1). The first ImPACT administered after concussion was used for analysis (average time between concussion and ImPACT assessment = 2.9 ± 2.3 days, range = 0–10 days). Recently, our university began implementing annual baseline reassessments for all athletes. If an athlete had multiple baseline assessments on record, the baseline assessment closest to the date of injury was used (days between baseline and concussion = 545.2 ± 403.5, range = 5–1495 days).

Statistical Analysis

We used paired-samples *t* tests to determine the total sample's average change from baseline to postconcussion for each ImPACT composite score. For each composite score, the mean baseline score of athletes who had postconcussion reliable decline was compared with the mean baseline score of athletes who had no postconcussion change or a reliable improvement using independent-samples *t* tests.

Regarding days missed for each ImPACT composite score, athletes who had postconcussion reliable decline were then compared with athletes who had no change or a reliable improvement using independent-samples *t* tests. The independent variable in these analyses was the athlete's group assignment (presence or absence of reliable decline), and the dependent variables were the mean baseline score and the mean days missed for each group. Additionally, we performed analysis of covariance to evaluate the main effect of the number of composite scores with reliable declines on days missed, covarying for sex, self-reported history of concussion, self-reported history of a diagnosed LD or ADHD, and days between concussion and ImPACT assessment. We elected to include covariates (sex, history of concussion, diagnosed LD or ADHD) regardless of their lack of unique significance because the literature identifies these factors as important predictors of both neurocognitive performance and differential recovery time after a concussion. We also left days between concussion and the first

Table 2. Participant Characteristics

Variable	Total n (%)	Learning Disability or Attention-Deficit/ Hyperactivity Disorder, No. (%)	Previous Concussions, No. (%)				
			0	1	2	3	4
Overall	84 (100.0)	18 (21.4)	44 (52.4)	28 (33.3)	7 (8.3)	3 (3.6)	2 (2.4)
Sex							
Males	62 (73.8)	10 (11.9)	35 (41.7)	21 (25.0)	3 (3.6)	2 (2.4)	1 (1.2)
Females	22 (26.2)	8 (9.5)	9 (10.7)	7 (8.3)	4 (4.7)	1 (1.2)	1 (1.2)

Table 3. Participants Exhibiting Reliable Cognitive Decline for Each Composite Score on ImPACT

Cognitive Domain	Composite Score, % (Mean ± SD)		Reliable Decline, %
	Baseline	Postconcussion	
Verbal memory	83.8 ± 11.5	79.5 ± 13.8[a]	33.3
Visual memory	71.7 ± 14.0	69.2 ± 14.9	20.2
Visual motor speed	37.1 ± 6.5	34.6 ± 9.5[a]	39.3
Reaction time	0.60 ± 0.14	0.69 ± 0.34[b]	47.6

Abbreviation: ImPACT, Immediate Post-Concussion Assessment Test (ImPACT Applications, Inc, Pittsburgh, PA).

[a] $P < .01$.

[b] $P < .05$.

ImPACT assessment as a covariate to account for subjective clinical decision making and, given the wide range of assessment points across the sample, the likelihood of athletes being at various points in the recovery process when assessed.

Data were examined for normality and linearity before analysis. Days missed was positively skewed (z[skew] = 13.7, $P < .001$); therefore, a Blom transformation was applied to this variable before analysis.[39] Significance was defined as $P < .05$ for all analyses, and corrections for multiple comparisons were conducted if necessary. Statistical analysis was performed using SPSS (version 22; IBM Corp, Armonk, NY).

RESULTS

We evaluated associations between sample demographics and variables of interest using χ^2 tests. No associations were found between sex, concussion history, LD or ADHD, and presence or absence of reliable decline for any ImPACT composite score (all P values >.05).

Descriptive statistics for baseline composite scores, postconcussion composite scores, and percentage of athletes exhibiting reliable decline are shown in Table 3. For the paired-samples *t* tests, we conducted the Bonferroni correction (4 comparisons), resulting in a significance level of $P < .0125$. Overall, performance on the verbal memory ($t_{83} = 3.10$, $P = .003$, d = 0.34, small-medium effect size) and visual motor speed ($t_{83} = 2.74$, $P = .008$, d = 0.32, small-medium effect size) tests declined postconcussion. Reaction time performance decreased after concussion but not significantly after Bonferroni correction ($t_{83} = –2.51$, $P = .014$, d = –0.36, small-medium effect size). Visual memory performance did not decline in this sample postconcussion ($P = .135$).

A substantial portion of our sample (40.5%) exhibited no reliable cognitive decline on any ImPACT composite score after concussion. Of the 84 athletes diagnosed with concussion, 20 (23.8%) exhibited a reliable decline on 1 ImPACT composite score, 16 (19.0%) exhibited reliable declines on 2 composite scores, 7 (8.3%) exhibited reliable declines on 3 composite scores, and 7 (8.3%) exhibited reliable declines on all 4 composite scores.

Baseline composite scores and days missed for athletes with or without postconcussion reliable decline are shown in Table 4. Athletes with a postconcussion reliable decline scored higher on baseline visual memory than athletes with no postconcussion change or a reliable improvement ($t_{82} = –2.35$, $P = .021$, d = 0.65, medium-large effect size). No baseline performance differences were evident between athletes with postconcussion reliable decline and those with no postconcussion change or a reliable improvement for verbal memory ($P = .420$), visual motor speed ($P = .112$), or reaction time ($P = .077$). We did not apply the Bonferroni correction to the independent-samples *t*-test comparisons because the participants composing the reliable-decline and the no-change or improvement groups differed in each of the 4 domains.

Days missed did not differ when comparing athletes who had postconcussion reliable decline with athletes who showed no change or a reliable improvement after concussion on verbal memory ($P = .084$), visual memory

Table 4. Baseline ImPACT Performance and Days Missed Based on Postconcussion Cognitive Change Group

Cognitive Domain	Postconcussion Cognitive Change Group, Mean ± SD		Mean Difference ± Standard Error
	Reliable Decline	No Change or Reliable Improvement	
Verbal memory			
n	28	56	
BL composite score	85.2 ± 10.8	83.1 ± 11.9	2.1 ± 2.7
Days missed	12.7 ± 11.5	9.6 ± 9.5	3.1 ± 2.4
Visual memory			
n	17	67	
BL composite score	78.6 ± 14.5	69.9 ± 13.4	8.7 ± 3.8[a]
Days missed	13.2 ± 12.7	10.0 ± 9.5	3.2 ± 2.7
Visual motor speed			
n	33	51	
BL composite score	38.5 ± 5.6	36.2 ± 6.9	2.3 ± 1.4
Days missed	10.4 ± 7.3	10.9 ± 11.8	0.5 ± 2.3
Reaction time			
n	40	44	
BL composite score	0.57 ± 0.07	0.62 ± 0.17	0.05 ± 0.03
Days missed	11.5 ± 11.4	10.0 ± 9.2	1.5 ± 2.2

Abbreviations: BL, baseline; ImPACT, Immediate Post-Concussion Assessment and Cognitive Test (ImPACT Applications, Inc, Pittsburgh, PA).

[a] $P < .05$.

($P = .193$), visual motor speed ($P = .374$), or reaction time ($P = .356$). Further, analysis of covariance demonstrated no main effect of the number of composite scores with a reliable decline on days missed ($P = .530$), and no significant covariates were identified (all P values $>.05$). In other words, athletes exhibiting reliable decline in most or all domains did not miss more days after injury than athletes exhibiting reliable decline in fewer or none of the cognitive domains.

DISCUSSION

We investigated differences in postconcussion outcomes based on mean baseline neurocognitive performance scores. Specifically, we examined whether groups of athletes who exhibited a reliable decline postconcussion on a given ImPACT composite score performed better at baseline than athletes who exhibited no change or improved. Athletes with a reliable decline after concussion had better baseline performance on just 1 composite score (visual memory). It is interesting that visual memory did not decrease in the total sample after concussion. This may indicate significant performance variability on visual memory tests. Previous evidence[18] has shown sex differences in visual memory performance, with males performing better than females. Additionally, both verbal memory and visual memory tend to exhibit poorer score stability over time based on reliability data relative to ImPACT processing speed measures.[8,9]

We also examined whether athletes with a reliable decline on a given ImPACT composite score took longer to achieve clearance for RTP. No statistical differences were noted in the number of days lost from athletic activity based on the presence or absence of a reliable decline on any ImPACT composite score. Additionally, athletes with a reliable decline in most or all of the ImPACT composite scores did not miss more time than athletes with a reliable decline in few or no composite scores. The descriptive data in Table 4 appear to show a clinically meaningful difference in days missed between those with and those without a reliable decline postconcussion, particularly for verbal memory and visual memory. However, because of the comparatively small number of participants in the reliable decline groups, the raw data are particularly susceptible to inflated means and standard deviations due to a few athletes who had protracted recoveries. Analyses using normalized outcome variables more accurately indicate the lack of a true statistical difference between these groups.

Only 60% of the athletes in our sample exhibited a statistically reliable deficit in performance on at least 1 ImPACT composite score based on the 80% reliable change index criteria of Iverson et al.[8] This is in contrast to the findings of previous researchers[3,13] who cited sensitivity of more than 80% and may be partly attributable to the range of days between the injury and initial postconcussion ImPACT test in our sample. In an early study of change scores on ImPACT, version 2.0, Iverson et al[8] observed that 75.6% of athletes exhibited reliable change relative to baseline on at least 1 composite score. However, unlike us, Iverson et al included the ImPACT postconcussion symptom scale composite score, which likely accounts for the discrepancy, given our exclusive focus on neurocognitive test performance. Regardless of methodologic differences, these discrepancies highlight the heterogeneity of postconcussion clinical presentation and neurocognitive performance, which are probably attributable to other factors (eg, injury severity, coincident symptoms, preinjury characteristics of the individual). For these reasons, a multifaceted approach to concussion management is always recommended.[37] The lack of association between cognitive decline and longer recovery time indicates that not all concussed athletes present with notable cognitive decline; their primary problem may be related to somatic-, vestibular-, or mood-based complaints.

The psychometric properties of ImPACT are 1 possible explanation for our findings. The 4 composite scores proposed by ImPACT have previously been questioned and may not represent a clear delineation of cognitive domains. Specifically, significant overlap in verbal and visual memory, as well as in visual motor speed and reaction time, provide evidence for a 2-factor structure: memory and speed composite scores.[40] Given that ImPACT does not contain any measure of simple reaction time but rather focuses on complex reaction time with decision-making components, the clinical utility of separating reaction time from visual motor speed on this CNT is perhaps most unclear. Evaluating recovery-time differences based on a modified factor structure is warranted. The limitations of ImPACT highlight the importance of clinicians' understanding the test's psychometric properties, particularly in the context of postconcussion performance interpretation.

Our results have implications for educating athletes on the purpose and clinical use of baseline testing, as well as managing recovery expectations after a concussion. We were unable to directly measure the possible effects of sandbagging or low effort on postconcussion performance or time missed from sport. Conceivably, athletes with low baseline scores in our sample included a mix of individuals extending sufficient effort but with poor cognitive abilities, individuals extending suboptimal effort, and possibly some who deliberately performed poorly in an attempt to sandbag. Steps must be taken to not only prevent sandbagging but also to promote maximum effort on baseline tests. If an athlete sustains a concussion and exhibits significant decline in multiple cognitive domains, clinicians can use these findings to help manage the athlete's expectations for recovery by sharing that individuals with broad cognitive deficits do not necessarily, on average, take longer to RTP than those with few or no areas of cognitive decline. We also recommend that clinicians, ideally in collaboration with a neuropsychologist trained in interpretation of their institution's neurocognitive assessment battery, carefully review the baseline test results of low-performing individuals to consider possible reasons for poor performance (eg, medical history indicates the presence of LD or ADHD) and the potential need to retest the athlete if suboptimal effort is suspected.

It is important to reiterate that we did not include athletes who were known or suspected to have purposely performed poorly on their baseline assessment. Previous authors[34,35] investigating athletes' ability to successfully sandbag found this was difficult to accomplish without detection by invalidity indicators. Our study likely included a broad range of athlete motivation levels. Future researchers may be able to investigate this phenomenon more directly if they can identify and report outcomes in athletes who either admitted to or showed evidence of sandbagging their baseline test and then later sustained concussions.

This study is limited by its retrospective design. We could not control when the first ImPACT assessment was administered after the incident concussion. Clinicians often differ in how they choose to use CNTs. Some use them early in the postinjury period for diagnostic assistance, whereas others prefer to use them later in the recovery process as an indicator for readiness to RTP. Indeed, the first assessment occurred over a wide range of days (0 to 10 days); future authors should prospectively investigate the relationship between CNT performance and days missed after concussion using multiple defined assessment points.

Also, this sample was disproportionately represented by males and football players and was limited to National Collegiate Athletic Association Division 1 collegiate athletes. Therefore, the findings may not generalize to both sexes, different sports, or all levels of participation. Although the nonnormalized descriptive statistic of days missed seemed to indicate clinically meaningful differences based on the presence or absence of reliable cognitive decline, further analyses with a larger and more diverse sample would contribute to our understanding of this relationship. Lastly, acute factors that may predict injury severity, such as loss of consciousness and posttraumatic amnesia, were not readily available for all patients in our study and may have contributed to recovery variability.

Despite these limitations, the present study may more closely represent actual clinical practice, in which variable assessment points are often used. In addition, most previous investigations have focused on the sensitivity of a CNT to detect injury or indicate the time needed for athletes to return to baseline performance; however, we focused on the clinically meaningful outcome of time missed from athletic activity.

ACKNOWLEDGMENTS

We thank the University Athletic Association for their continued support of our ongoing research and the student athletes for their participation. Study data were collected and managed using REDCap electronic data-capture tools hosted at the University of Florida: REDCap is a secure, Web-based application designed to support data capture for research studies, providing (1) an intuitive interface for validated data entry, (2) audit trails for tracking data-manipulation and -export procedures, (3) automated export procedures for seamless data downloads to common statistical packages, and (4) procedures for importing data from external sources. The University of Florida Clinical and Translational Science Institute receives grant support (National Institutes of Health National Center for Advancing Translational Sciences grant UL1 TR000064) for the REDCap project.

REFERENCES

1. Collins MW, Grindel SH, Lovell MR, et al. Relationship between concussion and neuropsychological performance in college football players. *JAMA*. 1999;282(10):964–970.
2. Alves WM, Rimel RW, Nelson WE. University of Virginia prospective study of football-induced minor head injury: status report. *Clin Sports Med*. 1987;6(1):211–218.
3. Van Kampen DA, Lovell MR, Pardini JE, Collins MW, Fu FH. The “value added” of neurocognitive testing after sports-related concussion. *Am J Sports Med*. 2006;34(10):1630–1635.
4. Meehan WP III, d’Hemecourt P, Collins CL, Taylor AM, Comstock RD. Computerized neurocognitive testing for the management of sport-related concussions. *Pediatrics*. 2012;129(1):38–44.
5. Bauer RM, Iverson GL, Cernich AN, Binder LM, Ruff RM, Naugle RI. Computerized neuropsychological assessment devices: joint position paper of the American Academy of Clinical Neuropsychology and the National Academy of Neuropsychology. *Clin Neuropsychol*. 2012;26(2):177–196.
6. Randolph C, McCrea M, Barr WB. Is neuropsychological testing useful in the management of sport-related concussion? *J Athl Train*. 2005;40(3):139–152.
7. Randolph C. Baseline neuropsychological testing in managing sport-related concussion: does it modify risk? *Curr Sports Med Rep*. 2011; 10(1):21–26.
8. Iverson GL, Lovell MR, Collins MW. Interpreting change on ImPACT following sport concussion. *Clin Neuropsychol*. 2003; 17(4):460–467.
9. Elbin RJ, Schatz P, Covassin T. One-year test-retest reliability of the online version of ImPACT in high school athletes. *Am J Sports Med*. 2011;39(11):2319–2324.
10. Schatz P. Long-term test-retest reliability of baseline cognitive assessments using ImPACT. *Am J Sports Med*. 2010;38(1):47–53.
11. Iverson GL, Lovell MR, Collins MW. Validity of ImPACT for measuring processing speed following sports-related concussion. *J Clin Exp Neuropsychol*. 2005;27(6):683–689.
12. Allen BJ, Gfeller JD. The Immediate Post-Concussion Assessment and Cognitive Testing battery and traditional neuropsychological measures: a construct and concurrent validity study. *Brain Inj*. 2011; 25(2):179–191.
13. Schatz P, Sandel N. Sensitivity and specificity of the online version of ImPACT in high school and collegiate athletes. *Am J Sports Med*. 2013;41(2):321–326.
14. Fazio VC, Lovell MR, Pardini JE, Collins MW. The relation between post concussion symptoms and neurocognitive performance in concussed athletes. *NeuroRehabilitation*. 2007;22(3):207–216.
15. Broglio SP, Macciocchi SN, Ferrara MS. Neurocognitive performance of concussed athletes when symptom free. *J Athl Train*. 2007; 42(4):504–508.
16. Chelune GJ, Naugle RI, Lüders H, Sedlak J, Awad IA. Individual change after epilepsy surgery: practice effects and base-rate information. *Neuropsychology*. 1993;7(1):41–52.
17. Sawrie SM, Chelune GJ, Naugle RI, Lüders HO. Empirical methods for assessing meaningful neuropsychological change following epilepsy surgery. *J Int Neuropsychol Soc*. 1996;2(6):556–564.
18. Covassin T, Elbin RJ, Harris W, Parker T, Kontos A. The role of age and sex in symptoms, neurocognitive performance, and postural stability in athletes after concussion. *Am J Sports Med*. 2012;40(6): 1303–1312.
19. Covassin T, Elbin RJ III, Larson E, Kontos AP. Sex and age differences in depression and baseline sport-related concussion neurocognitive performance and symptoms. *Clin J Sport Med*. 2012;22(2):98–104.
20. Lichtenstein JD, Moser RS, Schatz P. Age and test setting affect the prevalence of invalid baseline scores on neurocognitive tests. *Am J Sports Med*. 2014;42(2):479–484.
21. Moser RS, Schatz P, Neidzwski K, Ott SD. Group versus individual administration affects baseline neurocognitive test performance. *Am J Sports Med*. 2011;39(11):2325–2330.
22. Schatz P, Neidzwski K, Moser RS, Karpf R. Relationship between subjective test feedback provided by high-school athletes during computer-based assessment of baseline cognitive functioning and self-reported symptoms. *Arch Clin Neuropsychol*. 2010;25(4):285–292.
23. Schatz P, Moser RS, Solomon GS, Ott SD, Karpf R. Prevalence of invalid computerized baseline neurocognitive test results in high school and collegiate athletes. *J Athl Train*. 2012;47(3):289–296.

24. Zuckerman SL, Lee YM, Odom MJ, Solomon GS, Sills AK. Baseline neurocognitive scores in athletes with attention deficit-spectrum disorders and/or learning disability. *J Neurosurg Pediatr*. 2013;12(2): 103–109.
25. Elbin RJ, Kontos AP, Kegel N, Johson 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 Neuropsychol*. 2013;28(5):476–484.
26. Rabinowitz AR, Merritt VC, Arnett PA. The return-to-play incentive and the effect of motivation on neuropsychological test-performance: implications for baseline concussion testing. *Dev Neuropsychol*. 2015;40(1):29–33.
27. Bailey CM, Echemendia RJ, Arnett PA. The impact of motivation on neuropsychological performance in sports-related mild traumatic brain injury. *J Int Neuropsychol Soc*. 2006;12(4):475–484.
28. Reilly R. Talking football with Archie, Peyton, and Eli. ESPN Web site. http://espn.go.com/espn/news/story?id=6430211. Accessed November 2015.
29. Marvez A. How NFL players try to beat concussion tests. RealClearSports Web site. http://www.realclearsports.com/2011/04/21/how_nfl_players_try_to_beat_concussion_tests_88566.html. Accessed November 2015.
30. McCrea M, Hammeke T, Olsen G, Leo P, Guskiewicz K. Unreported concussion in high school football players: implications for prevention. *Clin J Sport Med*. 2004;14(1):13–17.
31. Llewellyn T, Burdette GT, Joyner AB, Buckley TA. Concussion reporting rates at the conclusion of an intercollegiate athletic career. *Clin J Sport Med*. 2014;24(1):76–79.
32. Meier TB, Brummel BJ, Singh R, Nerio CJ, Polanski DW, Bellgowan PS. The underreporting of self-reported symptoms following sports-related concussion. *J Sci Med Sport*. 2015;18(5): 507–511.
33. Hunt TN, Ferrara MS, Miller LS, Macciocchi S. The effect of effort on baseline neuropsychological test scores in high school football athletes. *Arch Clin Neuropsychol*. 2007;22(5):615–621.
34. Erdal K. Neuropsychological testing for sports-related concussion: how athletes can sandbag their baseline testing without detection. *Arch Clin Neuropsychol*. 2012;27(5):473–479.
35. Schatz P, Glatts C. “Sandbagging” baseline test performance on ImPACT, without detection, is more difficult than it appears. *Arch Clin Neuropsychol*. 2013;28(3):236–244.
36. McCrory P, Meeuwisse W, Johnston K, et al. Consensus statement on concussion in sport: the 3rd International Conference on Concussion in Sport held in Zurich, November 2008. *Br J Sports Med*. 2009; 43(suppl 1):i76–i90.
37. McCrory P, Meeuwisse W, Aubry M, et al. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport, Zurich, November 2012. *J Athl Train*. 2013;48(5):554–575.
38. Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) Test: Technical manual. Online ImPACT 2007–2012. ImPACT Applications Web site. https://www.impacttest.com/pdf/ImPACTTechnicalManual.pdf. Accessed November 2015.
39. Blom G. *Statistical Estimates and Transformed Beta-Variables*. New York, NY: Wiley; 1958.
40. Schatz P, Maerlender A. A two-factor theory for concussion assessment using ImPACT: memory and speed. *Arch Clin Neuropsychol*. 2013;28(8):791–797.

Address correspondence to Breton M. Asken, MS, ATC, Department of Clinical and Health Psychology, University of Florida, HPNP Building, PO Box 100165, Gainesville, FL 32610. Address e-mail to basken8@phhp.ufl.edu.