# Neuropsychological Testing in Mild Traumatic Brain Injury
## *What to Do When Baseline Testing Is Not Available*

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**Abstract:** Barth and colleagues' seminal study using baseline neuropsychological testing as a model for sports concussion management serves as the template for many collegiate sports medicine programs. However, there remains a significant need for an evidence-based strategy in cases where no baseline testing has been conducted. In this article, we further articulate such a model based on work with athletes at our Division I university. The foundation of the model involves base rates of impairment in a typical neurocognitive sports concussion battery, with decision rules that differ slightly for males and females. There is flexibility in the model such that its application can start during an acute period postconcussion when athletes are still potentially symptomatic, as well as after athletes self-report being symptom free. We use our population of collegiate athletes and the tests we administer as a framework to provide concrete values to the proposed algorithm based on specific tests, but the logic of our evidence-based model could easily be applied to other sports concussion populations and neurocognitive test batteries. Our proposed neuropsychological concussion management guidelines are evidence based, but also allow for accommodating trends in the literature which suggest that increasingly individualistic clinical concussion management approaches are most prudent.

**Key Words:** sports-related concussion, neuropsychology, mild traumatic brain injury, neurocognitive, evidence based

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Barth et al[1] laid out a framework for using baseline neuropsychological testing in sports concussion management, setting a standard that remains influential today. This model is now considered the gold standard for school-based sports medicine programs. Currently, most investigators use preinjury baseline neuropsychological testing compared with postconcussion testing as best practice for sports concussion management.[1–7] However, there are no clear guidelines for how to proceed when baseline data are not available, although a recent consensus paper by McCrory et al[6] acknowledged the need for such standards. The National Academy of Neuropsychology (NAN)[3] has relatedly noted that neurocognitive tests can play a meaningful role in concussion management even when baseline testing is not available, but no evidence-based model is offered.

In a recent article from our lab,[8] we laid out such a model. In the present article, we will provide a further articulation and clarification of that evidence-based model.

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Before laying out the model, we will provide a brief overview of existing approaches, discussing the merits of baseline testing, the timing of testing postconcussion, and the "value-added" of neuropsychological tests in a sports concussion context. Throughout the article, we will also discuss pros and cons relating to the use of baseline testing.

## USE OF BASELINE TESTING: STRENGTHS

As noted, the current gold standard for sports concussion testing involves the use of preinjury baseline neuropsychological testing.[1–7] And as others have articulated, a significant strength of the baseline testing approach is that it helps to control for idiosyncratic interindividual differences at baseline such as Attention Deficit Hyperactivity Disorder (ADHD), possible cumulative cognitive impact of prior concussions, cultural/linguistic differences, learning disorders, age, education, and proneness to psychiatric issues.[2,9] By controlling for such factors, the use of baseline testing should theoretically allow for a more sensitive assessment of the actual impact of concussion in specific individuals.

## USE OF BASELINE TESTING: LIMITATIONS

The baseline paradigm has been criticized because there is no empirical evidence that the use of baseline testing improves diagnostic accuracy,[10,11] reduces risk of further injury,[12] or predicts decline better than would be expected by chance alone.[9] Another limitation of the baseline paradigm is that the test-retest reliability for the types of intervals often used in sports concussion testing is not known for the individual neuropsychological measures that are typically used.[12–15] Test-retest reliabilities are usually assessed over about 4- to 8-week intervals, whereas baseline and postinjury intervals can be years apart. Also relating to the issue of reliability, the test-retest reliabilities for commonly used neurocognitive tests in sports concussion are often less than optimal. Mayers and Redick[14] note that a minimal standard for test-retest reliabilities when tests are used to make clinical decisions is 0.70 and above, a benchmark that is consistent with other suggestions in the research literature.[16(p. 65)] As an example for comparison with this standard, consider the ImPACT, the most commonly used measure in the neurocognitive assessment of sports concussion. In 1 study, the ImPACT was found to have generally acceptable levels of reliability when a group of healthy controls was tested 1 to 13 days apart (0.65 to 0.86 for the primary summary indices).[17] In contrast, test-retest reliability coefficients have been much lower when longer intervals between test administrations have been used. Values ranged between 0.23 and 0.38 for a 45-day test-retest interval,[15] and between 0.30 and 0.60 for a 2-year test-retest interval.[18] Of note, in the latter study the intraclass correlations were somewhat higher.

Test-retest reliabilities for more traditional paper-and-pencil neuropsychological tests have fared somewhat better than the ImPACT, as follows: Digit Span Test (0.80 to 0.91), Symbol Digit Modalities Test (0.72 to 0.80), Hopkins Verbal Learning Test-Revised (0.78), PASAT (0.80 to 0.90), and the COWAT (0.70 to 0.88).[13] Again, however, the time interval for establishing these reliabilities was considerably shorter than what typically occurs in the sports concussion framework.

Test-retest reliability coefficients are important whenever change in performance is evaluated because they are central to calculating the reliable change indices that are most often used to determine clinically significant change. The lower these reliability coefficients, the larger the confidence intervals, such that greater declines will be required postconcussion for reliable change to be detected. As such, tests with low test-retest reliability coefficients will be less sensitive than those with higher values to changes postconcussion.

Another limitation of baseline testing is that it is logistically complex and expensive. Also, practice effects from prior test exposure are problematic because these can reduce neuropsychological tests' sensitivity postconcussion.[19] To illustrate, we have often encountered athletes we have tested through our collegiate concussion program who have been administered the ImPACT at least 5 times during their primary and secondary school years as part of their participation in athletics. Each additional exposure to these tests, even when alternate forms are used, reduces their sensitivity. Because of such overexposure, an athlete who then suffers from a concussion and is tested again using such familiar measures will be much less likely to show a decline from baseline. More research is clearly needed to evaluate this type of overexposure of tests and how much this reduces their sensitivity to actual change after concussion.

As a further illustration of this overexposure issue, we have research under review from our lab where we have shown that traditional neuropsychological tests are more sensitive to the effects of concussion than computerized tests such as the ImPACT. We found that 29% of the collegiate athletes in our sample showed a decline on at least 1 test from the traditional neuropsychological battery in cases where the athletes did not show any declines on the ImPACT. This was the case when the number of test indices from each battery was kept constant. It is not clear from these data that the reduced sensitivity of the ImPACT was due to overexposure relative to the standard paper-and-pencil neurocognitive tests, but this is certainly a very real possibility.[20]

Despite the baseline testing model's strength in controlling for interindividual differences, it has some limitations. With this in mind, the use of neuropsychological tests in the sports concussion framework when no baseline is available should be considered.

## TIMING OF POSTCONCUSSION TESTING

There is no unanimous consensus on the timing of postconcussion neurocognitive testing, although most investigators now recommend waiting to conduct neurocognitive testing until athletes are symptom free by self-report. The rationale for this approach is that, because athletes will not be returned to play (RTP) if they are self-reporting symptoms, there is no point in conducting neurocognitive testing. Under these circumstances, even if athletes are back to baseline neurocognitively, they will not be RTP.[5,6] With that said, McCrory et al[6] allow for some flexibility in this general guideline, noting that neurocognitive testing before symptom resolution may be warranted in some cases (especially in children and adolescents) because such testing could help with school and home management. An additional consideration related to issues already raised about overexposure to tests, testing in the early postconcussion interval could contaminate future testing because of practice effects.

Other investigators have recommended that neurocognitive testing ideally should be conducted in the acute injury period to help determine the severity of the concussion, and then again when the athlete is symptom free to help with RTP decisions.[2] However, it is not clear from these guidelines when during the acute injury period that testing might ideally occur. The ImPACT Test Technical Manual[21] and the "Best Practices" page from the ImPACT Web site (https://www.impacttest.com/pdf/improtocol.pdf), also recommend postconcussion ImPACT testing before symptom resolution, within 24 to 72 hours postconcussion, to assess whether declines have occurred from baseline and to help with concussion management in general. They also recommend testing after this acute period once the athlete is symptom free both at rest and with cognitive exertion.

## THE "VALUE-ADDED" OF NEUROPSYCHOLOGICAL TESTS IN A SPORTS CONCUSSION FRAMEWORK

Randolph and colleagues[11,12] have been the most prominent critics of the "value-added" from neuropsychological testing within the sports concussion management framework, asserting that RTP decisions should strictly be based upon athletes' self-reported symptoms. Such an approach, however, seems misguided because a significant percentage of concussed athletes who report full symptom resolution still show objective neurocognitive deficits. This is the case using both the baseline/postconcussion testing framework where declines from baseline are found,[7,22] but also in cases when no baseline is available where concussed athletes show worse neurocognitive performance than control subjects.[23]

Another concern with relying exclusively on athletes' self-reports to make RTP decisions is that some athletes are motivated to minimize symptoms after concussion so that they will more quickly RTP, a process articulated in Echemendia and Cantu's[24] "Dynamic Model for Return-to-Play Decision Making." In addition, self-reports of cognitive functioning are typically only weakly correlated with actual performance on objective cognitive tests, even in individuals who are motivated and who have not experienced any insult to the brain.[25]

## WHAT TO DO WHEN BASELINE TESTING IS NOT AVAILABLE FOR NEUROCOGNITIVE CONCUSSION MANAGEMENT

With the above considerations in mind and addressing an important clinical need identified by others, as well,[6,13,26] we now turn to an overview of our model for the use of neuropsychological tests in a sports concussion framework when no baseline is available.[8] We have derived this model using an evidence-based approach based on data collected over more than 10 years in a collegiate sports concussion program. Rather than being the final word on the topic, our approach represents a step in a process that should evolve as new empirical knowledge emerges.

In Figure 1, we illustrate our algorithm. It is based on a battery that includes both computerized and paper-and-pencil tests. We will provide a brief description of each test (more details can be found in Arnett et al[8]), and then describe the evidence basis for each step of the algorithm. We provide separate decision rules for males and females because the base rates of impairment differ by sex in our sample. Beyond sex, there are factors that could influence the interpretation of neurocognitive test results including depression, number of prior concussions, and the presence of ADHD/learning disorders. However, any systematic treatment of these issues goes beyond the scope of this article. Future work will be necessary to address this issue systematically for the sports concussion context. The study on which we base some of the framework of the algorithm

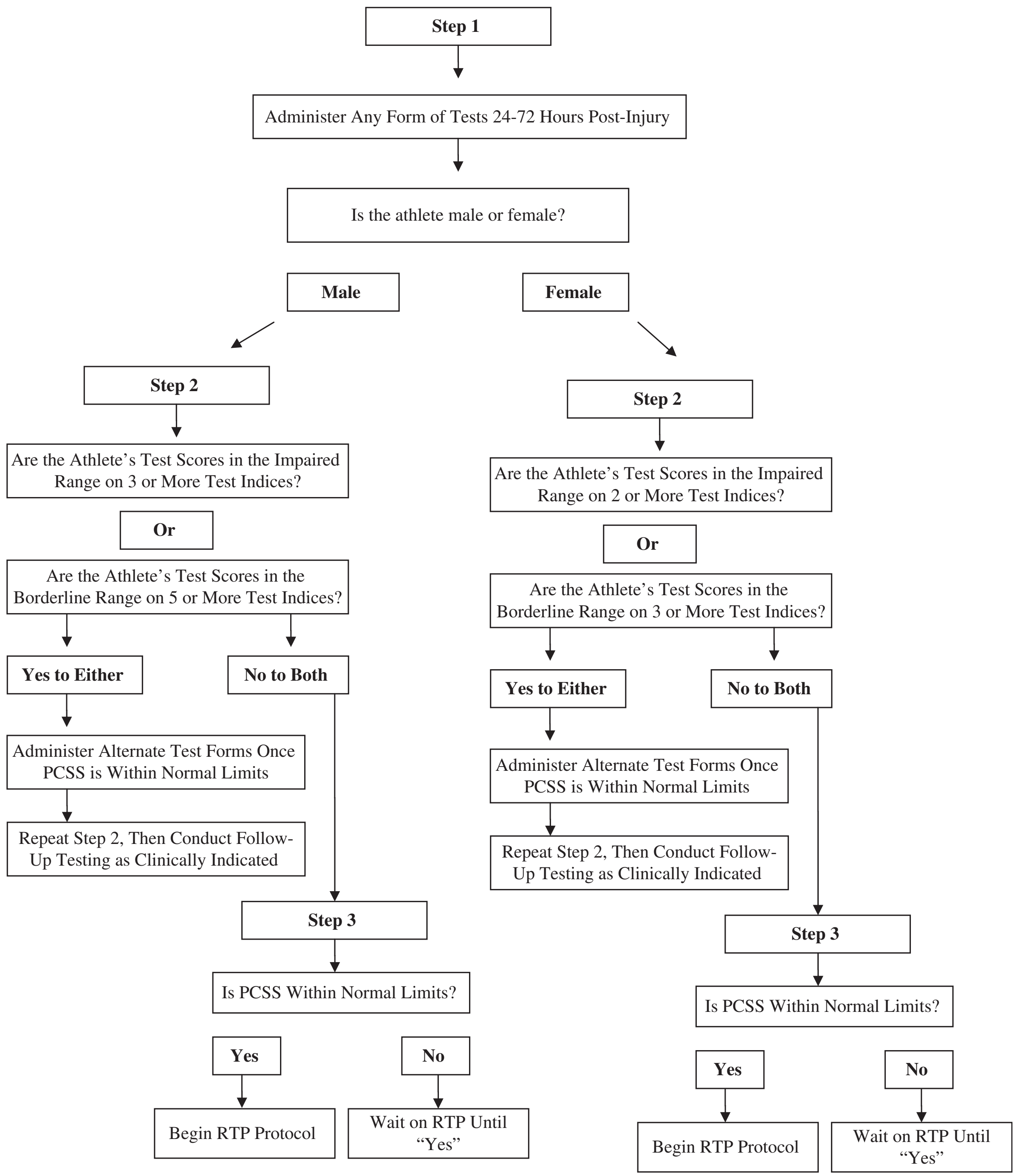


**FIGURE 1.** Postconcussion neuropsychological testing algorithm when no baseline is available. Used with permission from Arnett et al,[8] Springer.



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was conducted in compliance with university Institutional Review Board requirements and American Psychological Association ethical guidelines.

## MEASURES

The test battery that serves as the basis for our model includes both computerized and paper-and-pencil measures. In contrast to computerized tests, more traditional paper-and-pencil measures are less widely used because they require face-to-face administration; however, including such tests is likely to increase the sensitivity of the battery. Despite the complexity involved with including paper-and-pencil tests, we include them here because we have found that they can result in a substantial increase in sensitivity to cognitive impairment after sports concussion relative to reliance solely on computerized tests.[20] In addition, if neuropsychological tests are only used postconcussion (as opposed to both baseline and postconcussion) then the cost of administration is considerably lower.

### Computerized Tests

Computerized tests include the ImPACT[27] and the Vigil Continuous Performance Test.[28] The Verbal Memory Composite, Visual Memory Composite, Visuomotor Speed Composite, and Reaction Time Composite from the ImPACT were used. Average delay (a reaction time index) was used for the Vigil.

### Paper-and-Pencil Tests

These measures include: the Hopkins Verbal Learning Test-Revised[29] (total correct immediate and delayed recall), the Brief Visuospatial Memory Test-Revised[30] (total correct immediate and delayed recall), the Symbol-Digit Modalities Test[31] (total correct within 90 s), a modified Digit Span Test[32] (total correct forward and backward sequences), the PSU Cancellation Task[33] (total correct within 90 s), Comprehensive Trail Making Test Trails 2 and 4 or 3 and 5[34] (completion times for both parts), and the Stroop Color-Word Test[35] (time to completion for both Color-Naming and Color-Word conditions). In sum, a total of 17 test indices were used across computerized and paper-and-pencil measures, with alternate forms of tests used where available.

### Self-report

The Post-Concussion Symptom Scale (PCSS) was used to measure postconcussion symptoms, and includes a list of 22 commonly reported postconcussion symptoms. Examinees rate the extent to which they are currently experiencing each symptom on a scale from 0 to 6, with 0 indicating the absence of the symptom, and 6 being severe.

## ALGORITHM OF DECISION RULES

As illustrated in Figure 1, each step of the algorithm involves an action first and then a question (step 1), or questions first and then an action depending on the answer to the question (steps 2 and 3).

### Step 1

#### Action

Administer the test battery at 24 to 72 hours postinjury.

#### Question

Is the athlete male or female? As noted in Figure 1, different decision rules apply for males and females because of sex differences in base rates of impairment.

#### Evidence Basis

Most work in humans has shown that the peak cognitive impact postconcussion usually occurs within 24 to 72 hours postinjury,[1,19,36,37] with some individual variability noted.[37] Animal models are consistent with these findings, demonstrating that many aspects of the neurochemical cascade in the brain after concussion peak at about 48 hours postinjury, with the decrease in glucose metabolism occurring at about 48 hours postinjury and also correlated with cognitive dysfunction in adult rats.[38–40]

#### Rationale

One advantage of conducting neurocognitive testing of athletes during this time interval is to provide a measure of the full impact of the concussion on the brain. Athletes who show more normative impairments at this acute stage could be managed more conservatively once RTP procedures have begun than those who were closer to being back to their likely premorbid cognitive level at this stage. Also, if the athlete performs normally relative to base rates at this early stage, no further neurocognitive testing would need to be conducted postconcussion. RTP decisions could then be made based on other factors (eg, self-reported symptoms, vestibular signs, etc.). If athletes are back to baseline neurocognitively, even at this early stage, then more rapid RTP could potentially occur. Although an athlete's medical well-being must always be the most important consideration of sports medicine professionals, athletes performing at a high level of sport (eg, Division I college, such as the athletes on which our algorithm is based) could suffer significant harm in terms of their status on the team and ability to compete in important games and maintain their scholarships if they are held out of play for an unnecessarily long period of time.

Another advantage of conducting systematic testing during this acute period postconcussion and at other systematic time points, is that the neurocognitive results after any future concussion the athlete suffered could be compared with the results following the previous concussion to assess whether any increase in the range and severity of cognitive impairments postconcussion had occurred. If athletes are tested at different points postconcussion, then such systematic comparisons would not be possible. However, athletes can be treated more conservatively if they have had multiple concussions and then show an increased range and severity of cognitive impairments at the same time points postinjury with each successive concussion.

Another benefit of testing collegiate athletes during this relatively acute period postconcussion is that if there is objective evidence for neurocognitive impairment at this point, then the neurocognitive data could be used to help athletes get temporary academic accommodations while symptomatic. Possible accommodations include things like deferral of exams and other assignments, testing in a room free from distraction, and extra time on exams, among others.

We recognize that many investigators and clinicians recommend waiting to conduct neurocognitive testing until athletes self-report being symptom free.[26] The rationale for this is that athletes will not be RTP when they are still self-reporting symptoms, so why bother with objective testing



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until they are symptom free? Nonetheless, we assert that such testing can still be valuable for the above reasons that go beyond simply making an RTP decision.

An additional drawback cited for testing while athletes still report being symptomatic is that such testing could exacerbate the athlete's symptoms. In fact, we have found that significantly more concussed athletes (30%) report increased postconcussion symptoms after neurocognitive testing than athletes who have not had concussions (about 12%).[20] Still, even in this study a majority (about 70%) of concussed athletes did not show increased symptoms after testing suggesting that, for most athletes, the mental exertion that results from a typical neurocognitive testing is not going to result in a reliable increase in symptoms.[20]

Even for athletes who do show increased symptoms as a result of neurocognitive testing, we assert that the value of such acute testing, as outlined above, outweighs the potential minor risk of a temporary increase in symptoms. One caveat to this, of course, involves cases where symptoms are so extreme that testing could be harmful in exacerbating already severe symptoms, or where the nature of such symptoms would likely substantially interfere with test performance (eg, severe dizziness, nausea, or headache, among others). This is where taking an individualistic concussion management approach again becomes important.[41]

With all this said, we recognize that many clinicians will still want to defer formal neurocognitive testing until athletes report being symptom free. In these cases, our algorithm can still be applied, with clinicians simply starting the algorithm at the first question, "Is the athlete male or female?" (Fig. 1).

## Step 2

### Question

Are the athlete's test scores in the impaired or borderline range (defined below) on a certain number of indices? Rather than detail every permutation here, we refer the reader to Figure 1.

### Action

Administer alternate test forms once the PCSS is within normal limits (defined below) if the athlete receives a "yes" response at step 2 for either the impaired or borderline criterion. If there is a "no" response at this step to both criteria, then one proceeds to step 3.

### Evidence Basis

Many athletes still show evidence for objective cognitive impairment even when they report being symptom free[22]; thus, relying only on self-report can lead to an inaccurate assessment of an athlete's actual cognitive functioning. In addition, there has been consistent replication of a low correlation between objective neurocognitive test performance and self-reported neurocognitive functioning. Athletes should thus have to objectively perform within normal limits neurocognitively before RTP procedures being initiated. Following this recommendation after a "yes" response, the algorithm indicates, "Repeat Step 2, Then Conduct Follow-Up Testing as Clinically Indicated."

### Rationale

First, it is important to keep in mind that the algorithm is slightly different at step 2 for males and females because there are different base rates of impairment by sex in our sample. To make these determinations, we examined baseline performance in 495 collegiate athletes on the same test battery.[8] Impairment on a test was defined as performing 2 SDs or more below the mean of other athletes; borderline impairment was defined as 1.5 SD or greater below the mean.

In our sample, < 10% of males had 5 or more borderline scores, and < 10% of females had 3 or more borderline scores. In addition, < 10% of males had 3 or more impaired scores, and < 10% of females had 2 or more impaired scores. These base rates served as a foundation for the decision rules in our model. Thus, male athletes who are tested postconcussion who show impairment on 3 or more tests and female athletes who show impairment on 2 or more tests evidence highly unusual performance that is likely to reflect the impact of their concussion (Fig. 1). Similarly, male athletes who are tested postconcussion who show borderline scores on 5 or more tests and female athletes who show borderline scores on 3 or more tests display highly unusual performance that is likely to reflect the impact of their concussion. The application of these data in decision rules is shown at step 2 in Figure 1.

### Other Considerations

It is optimal for concussion programs adopting this algorithm to use neurocognitive base rates of impairment data collected from athletes in their specific programs because the data used are likely to be most valid for that group of athletes. If such base rates differ from what we report, relevant values could simply replace what we suggest in the algorithm. Of note, other studies using test batteries comparable in length to ours have reported similar base rates of impairment.[42–44]

## Step 3

### Question

Is PCSS within normal limits?

### Action

If the answer to this question is "yes," then the recommendation is to begin the RTP protocol. If the answer is "no," then the recommendation is to wait on starting the RTP protocol until the PCSS is within normal limits.

### Evidence Basis

The determination of "within normal limits" is made using normative data from our sample of collegiate athletes at baseline on the PCSS. Similar to our comment above concerning the ideal framework being the use of local norms to determine base rates, normative data from local samples would ideally be applied here to the PCSS. Scores falling within the broad average range (ie, standard score of 80 or above) are considered "within normal limits."

### Other Considerations

One complicating issue involves cases where athletes have a "yes" response at step 2 (meeting the below base rate impaired or borderline criterion), yet report being within normal limits in terms of their symptom report. Given that the recommendation after such an outcome is to "Administer Alternate Test Forms Once PCSS is Within Normal Limits," how does one proceed? There are no clear evidence-based guidelines for how to proceed here in terms of the precise timing of the next postconcussion testing point. One possibility would be to test the athlete again between 5 and 10 days postconcussion, given that many studies show that most collegiate athletes show full cognitive recovery by that point.[1,19,33,36,45–47] Still, a significant minority of collegiate athletes do not recover within that window and take longer than 2 weeks for their neurocognitive functioning to normalize.[47,48] Thus, more research will clearly be needed to refine this broad guideline.

Studies that examine the duration for normalization of brain functioning in athletes who report being normal in terms of symptom report but show impairments neurocognitively would be ideal. Given the current state of the literature, the most prudent approach would be to rely more on individualistic clinical concussion management strategies used by skilled clinicians to determine temporal sequencing of testing in these cases.[41] Factors such as the urgency with which a RTP decision needs to be made (eg, if a crucial game is imminent vs. the athlete's sport not being in season), as well as other individualistic factors (eg, prior concussion history, the presence of clinically significant depression) would need to be considered. The impact of practice effects must also be considered in this determination, as practice effects are more likely to occur at short time intervals and with each additional testing session. Thus, the model allows for considerable flexibility at this stage due, in part, to the absence of clear research evidence to guide decision making, but also due to idiosyncratic factors that are nearly always going to be at play in the clinical management of concussion.

## STRENGTHS AND LIMITATIONS

A strength of our algorithm is that it provides systematic decision rules, and leaves much room for individualistic concussion management; we spell out a number of examples where such factors come in to play. A limitation of our approach is that the neuropsychological test battery we recommend is relatively lengthy, logistically complex, and personnel intensive because someone needs to administer the battery face-to-face rather than it being administered by computer. However, because baseline testing is not conducted, its complexity is reduced. Also, the algorithm can be adapted to different test batteries and different athlete groups when base rates of impairment data can be derived from such groups.

## FUTURE DIRECTIONS

Studies that validate our algorithm in other samples independent of our lab group are needed, particularly to test groups of collegiate athletes with and without concussions, and then testing them at the same time intervals suggested by our model. Examining base rates of impairment and base rates of decline on the test battery in individuals with common comorbid conditions such as ADHD and/or learning disorders will also be necessary.

The recommendations we make for this algorithm are necessarily tentative because there is limited evidence available for some aspects of the model (eg, the ideal timing of postconcussion testing during the acute injury period, ideal temporal sequence of testing once athletes are normative symptomologically, but still impaired neurocognitively). Nonetheless, we hope that our algorithm can provide a template for improving neurocognitive concussion management in collegiate athletes, especially in those cases where no baseline testing has been conducted.

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