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ORIGINAL PAPER

Recovery from sports concussion in high school and collegiate athletes

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Abstract
Introduction: Neuropsychological testing is a valuable tool in concussion diagnosis and management. ImPACT, a computerized neuropsychological testing program, consists of eight cognitive tasks and a 21-item symptom inventory.
Method: ImPACT was used to examine the cognitive performance of 104 concussed athletes at baseline, 2, 7 and 14 days post-injury. Dependent measures included composite scores from the ImPACT computerized test battery, as well as a total symptom score from the Post-Concussion Symptom Scale.
Results: Differences between baseline and day 2 post-injury scores were observed for all ImPACT composites (Verbal memory-VERM, visual memory-VISM, processing speed-PROC and reaction time-RT) as well as in total symptom score (SX). At day 7, concussed athletes continued to perform significantly poorer on VERM, VISM, RT and SX. At day 14, only VERM scores were significantly different from baseline.
Conclusions: Cognitive performance deficits in concussed athletes may persist to 7 and even to 14 days in some cases. In addition to symptom status, the athlete's post-concussion cognitive functioning should be considered when making return-to-play decisions.

Keywords: *Concussion, sport, TBI*

Introduction

American athletes suffer ~300 000 concussive injuries on a yearly basis and 19% of participants in contact sports such as football and rugby are likely to suffer a mild traumatic brain injury (TBI) during a season [1]. The majority of concussions occur at the high school level, where well over one million high school students participate in football. At the high school level, over 62 000 football players receive a concussive injury each year [2], whereas 34% of collegiate football players have been diagnosed with one concussion and 20% have been diagnosed with multiple concussions [3]. The frequency of this injury, as well as a lack in scientific understanding of recovery mechanisms and physiology, has lead to increased attention from the sports medicine world.

The most hotly debated issue in sports concussion revolves around efforts to establish a scientifically grounded guide for return-to-play parameters, given that a second impact prior to recovery from an initial concussion can have deleterious effects. This idea is based on recent animal models which suggest that symptoms of sports concussion are likely related to acute metabolic dysfunction [4]. Post-traumatic hyperglycolysis and concomitant decreased cerebral blood flow have been implicated for the cause of this dysfunction. It has been hypothesized that metabolic dysfunction, until fully resolved, may heighten the athlete's neurological vulnerability if a subsequent trauma (even minor) is sustained [5]. The controversial second impact syndrome [6] and less severe, though potentially incapacitating post-concussion syndrome are two risks involved with returning an athlete to play

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before complete recovery. Although long-term deficits in the form of post-concussion syndrome have been observed from a single concussive event [7], it is typically assumed that proper management of injury should lead to a good prognosis and minimal, if any, long-term neurological deficits. Therefore, the precise management of concussion is essential in safeguarding athletes from permanent cognitive impairment or even death.

A recent study published in the *Journal of the American Medical Association* examined the recovery times of concussed collegiate football players [8]. Ninety-four players were included in the study and were compared with 56 age-matched controls. The study's findings concluded that injured athletes had completely recovered from their concussive injury by the fifth day post-injury. Complete recovery was defined as having achieved baseline performance levels on the Graded Symptom Checklist (GSC), paper and pencil neurocognitive tests (HVLT, Trail-Making Test Part B, Symbol Digit Modalities Test, Stroop Colour-Word Test, COWAT) and the Balance Error Scoring System (BESS). All symptom and neurocognitive deficits had resolved by day 5 post-injury and the BESS scores had returned to baseline between days 3–5 post-injury.

Previous paper and pencil studies conducted by Macciocchi [9], Collins et al. [3], Lovell [10], Echemendia and Petukian [11] and McCrea and Kelly [12] have demonstrated measurable neurocognitive deficits that are typically evident within 1–2 days post-injury that invariably resolve by day 5 post-trauma. No prior studies examining paper and pencil measures have revealed significant neurocognitive deficits persisting beyond this time period. Notably, however, with the exception of Macciocchi et al. ($n = 183$) and McCrea's recent analysis ($n = 94$) sample sizes have been small and adequate group comparisons have been limited.

Moreover, two of the most widely utilized return-to-play guideline scales currently are the Colorado Guidelines [13] and the American Academy of Neurology Guidelines [14]. Each of these scales diagnose concussions on a three point scale with a grade 1 (mild), a grade 2 (moderate, no LOC) and a grade 3 (any LOC) concussion. For grade 1 concussions, the Colorado and AAN guidelines permit return-to-play the same day of injury if symptoms abate or do not appear within 20 minutes of injury. Further, both sets of guidelines permit all asymptomatic athletes sustaining a grade 2 concussion to return to athletic participation within 1 week of injury. It is noteworthy that many concussion grading scales and recent studies concluded all athletes should heal from concussive injury within 7 days. This is the traditional period of time between football games, incidentally the sport most frequently linked with this injury at levels from junior high to the NFL.

A recent editorial in *JAMA* scrutinized the reliance on grading scales in managing concussive injuries. While these grading scales were initially useful in increasing knowledge about concussion and its signs and symptoms, they were formed solely by clinical experiences and lacked the utilization of scientific research [15]. Also, the scales generalize concussions for all ages, playing levels, and genders. Differences in the brain's ability to regain cognitive functioning and symptom reporting practices between individuals are not taken into account in any of the aforementioned return-to-play scales [16]. For example, a recent manuscript has found significant differences in recovery rates between high school and collegiate athletes [17].

The purpose of this paper is to examine the time of recovery from concussive injury for high school and collegiate athletes participating in a variety of sports. The vast majority of concussive injuries are suffered at the high school and collegiate levels of participation, yet many coaches, athletic trainers and team doctors may be unaware of the severe consequences that can arise in returning a player to participation prematurely. Recent studies claim that the average concussion ameliorates within 1 week of onset and many concussion grading scales also clear mildly and moderately injured athletes for participation within 1 week. It is the authors' hypothesis that even mild concussions often require more than 7 days to completely resolve (indicated by a return to baseline level of functioning). The results of this study will hopefully add to a body of literature that has raised awareness of the possible prolonged effects of concussive injury and further ensure that injured athletes are given a sufficient amount of time to recover before returning to the field of play.

Methods

Measures

This study was performed utilizing the ImPACT computerized neuropsychological testing platform which is designed to identify cognitive impairment following a concussive injury [18]. Through an ~20-minute series of tests, ImPACT provides data on cognitive functioning in the often-affected areas of visual and verbal memory, working memory, processing speed, visual motor skills and reaction time. Also, athletes were administered the Post-Concussion Symptom Scale, a detailed 21 symptom checklist that is widely utilized throughout the National Football League National Hockey League and amateur sports leagues [19].

Through the athlete's performance on the neuropsychological test battery, ImPACT calculates four composite scores detailing performance in the four distinct cognitive domains. The verbal memory composite is generated by performance on tests of word learning, word recognition memory and letter memory. The visual memory composite is comprised of tests revealing shape learning and memory, visual working memory and visual associative memory. The reaction time index is measured in hundredths of a second and consists of weighted performances on three different reaction time sub-tests. The processing speed composite is also measured in hundredths of a second and shows performance in visual-motor processing speed and visual scanning speed [17].

During the 1st International Symposium on Concussion in Sport, the council was concerned about various problems encountered with neuropsychological testing including sensitivity, specificity and learning/practice effects [20]. The symposium stated that traditional methods of neuropsychological testing, namely paper and pencil tests, may be susceptible to practice and learning effects. Based upon these prior data, sole use of paper and pencil neurocognitive measures may increase the risk of false negatives and may offer limited assessment sensitivity.

In a series of recent papers, ImPACT (Version 2.0) was shown to be sensitive to the mild effects of sports-related concussion. Specifically, when compared to non-injured controls and to baseline levels of functioning, 64 athletes sustaining mild concussion had reduced memory functioning at three post-injury intervals (36 hours, days 4 and 7) [21]. Moreover, controls included in the above study did not demonstrate any significant practice effects and produced consistent scores across the three testing sessions. In a follow-up study, other ImPACT composite scores (visual memory, reaction time and processing speed) were also able to distinguish mildly concussed high-school athletes from control peers [22].

Also, a recent manuscript detailed the reliability for each of ImPACT's composite scores [23]. This report concluded that no practice effects were found in three of four composite scores for cognitive functioning. One criterion of the current study that each participant met was the presence of a preinjury baseline testing session. With this baseline standard, the athlete's preinjury performance served as his or her own control throughout the study. By acquiring baseline data, the study avoided the difficulty of matching a control group to the injured sample in terms of age, gender and concussion background.

Participants

The current study was comprised of 104 high school and collegiate athletes who experienced a cerebral concussion while participating in an athletic event. Each athlete attended a high school or college which participated in the UPMC Sports Medicine programme. A master database of ImPACT data, acquired from these high schools and colleges, was examined in order to form the study's sample. Subjects were chosen based upon the presence of a pre-season baseline examination, a diagnosed concussive injury during their season of play and three subsequent testing sessions after sustaining their injury. Each concussed athlete included in the study consulted with one of the UPMC concussion specialists.

The concussive injuries were accumulated over a 30 month period spanning from September 2001 – February 2004. The group was predominantly male, with 91 participants (87.5%) and the average age was 16.11 years ($SD = 2.22$). On average, the sample had completed 9.74 years of education ($SD = 1.89$). The sample represented seven different sports, with football being represented most often ($n = 83$, 79.8%). Soccer ($n = 6$), basketball ($n = 5$), wrestling ($n = 5$), hockey ($n = 3$) and field hockey ($n = 1$) followed. One athlete's sport was unidentified.

In terms of previous concussive history, the group showed trends similar to predicted values. Seventy athletes (67.3%) had no previous history of concussion. Thirty-four athletes (32.7%) had a prior history of one concussion and 13 (12.5%) had more than one prior concussion. Regarding characteristics of prior concussions, 11 (10.6%) suffered loss of consciousness, 20 (19.2%) experienced overt confusion, 14 (13.5%) presented with anterograde amnesia and eight (7.7%) had retrograde amnesia following their previous concussive injuries.

Design and procedure

Every participant in this study underwent a baseline or pre-injury evaluation using the ImPACT battery during their sport's off-season. Upon receiving a concussion, the injured athletes again underwent computerized testing at least three times after being injured. On average, the athletes were first tested at day 2 ($M = 2.42$ days, $SD = 3.14$), 1 week ($M = 7.58$ days, $SD = 4.49$) and 2 weeks ($M = 14.35$ days, $SD = 7.34$) post-injury. To determine when an athlete was completely recovered from concussion, their post-concussion data was compared to their baseline testing information. All athletes diagnosed with an in season concussion did not return to play until they were symptom free at rest and exertion and their ImPACT data had returned to baseline levels.

The computerized neuropsychological test battery was administered to each athlete by a clinical neuropsychologist, athletic trainer or physician thoroughly trained in the administration of the measures. As ImPACT is a self-administered test battery, all information is gathered in a standardized manner. Further, test scores are automatically generated into a complete clinical report, reducing the possibility of variation in administration or data collection between participating sites.

Results

Concussion descriptions

The majority of concussions suffered were diagnosed as Grade 1 ($n=78$, 75%) according to the guidelines set forth by the American Academy of Neurology. The remainder were diagnosed as grade 2 ($n=16$, 15.4%) and grade 3 ($n=9$, 8.7%) concussions. Only nine participants experienced a loss of consciousness and each lasted less than 20 seconds. Of the sample, 53 (51.0%) athletes experienced confusion following their injury. Anterograde amnesia was present in 23 injured athletes (22.1%) and 19 presented with retrograde amnesia (18.3%) following their concussive injury. Data for on-field markers of injury was missing for 11 study participants.

Main effects analysis

All statistical analyses were completed using Statistica 6.1 [24]. A Multiple Analysis of Variance (MANOVA) model was employed to evaluate the overall significance of time in regards to the athletes' performance on the neuropsychological test. Further, a Bonferroni analysis was employed post-hoc to test for any significant differences in cognitive performance between the baseline scores and the three post-concussions trials. The Bonferroni test is a very conservative test of pairwise comparisons and was used to supply a strict adjustment for experimentwise error.

Table I presents the detailed descriptive statistics for verbal and visual memory, processing speed, reaction time and symptom ratings. Also, the means and standard deviations for the concussed athletes across baseline and three post-concussion testing sessions are shown in Table I. Pairwise comparisons between concussed athletes at baseline and the three follow-up testing sessions are illustrated in figures 1–5.

For the verbal memory composite score, there was a significant difference in performance across the evaluation period, $F(3{,}309)=37.74$, $p<0.01$. The sample showed a significant reduction in scores throughout the three different testing sessions. Pairwise comparisons (Figure 1) revealed significantly lower memory scores at day 2 ($p<0.01$), day 7 ($p<0.01$) and day 14 ($p<0.01$).

In terms of visual memory, there again was a significant difference in test performance between baseline and post-concussion evaluations, $F(3{,}225)=19.05$, $p<0.01$. Pairwise comparisons (Figure 2) revealed a significant difference between baseline and the testing sessions at day 2 ($p<0.01$) and day 7 ($p<0.01$) post-injury. There was no significant difference between visual memory at baseline and 14 days post-injury. The visual memory composite was only analysed for 76 athletes because it was only recorded by ImPACT versions 2.0 and later. If an athlete took ImPACT before the release of version 2.0, they were not given a visual memory composite during that testing session and subsequently could not be analysed in the MANOVA.

For the processing speed composite score, there was a significant main effect for time, $F(3{,}309)=26.74$, $p<0.01$. Through pairwise comparisons (Figure 3), there was a significant reduction in performance between baseline and day 2 ($p<0.01$) post-injury. There was no significance between the performances at baseline and the second post-injury session. At 14 days post-concussion, the processing speed composite had increased compared to baseline performance ($p<0.05$). Of note is that the processing speed score achieved during the second testing session at day 7 showed significance ($p<0.0007$) when compared to the post-concussion test on day 14.

With regards to reaction time, there was a significant difference in test performance between the baseline and post-concussion evaluations, $F(3{,}309)=28.07$, $p<0.01$. Specifically, pairwise

Table I. Average ImPACT composite scores and post-concussive symptoms.

Variable	Baseline	Day 2	Day 7	Day 14
Verbal memory composite	85.75 (8.59)	72.00 (14.87)	75.88 (13.79)	79.43 (13.60)
Visual memory composite	74.04 (13.82)	61.20 (12.92)	66.96 (15.92)	72.29 (14.31)
Processing speed composite	35.05 (6.90)	30.28 (9.06)	33.99 (8.10)	36.96 (8.30)
Reaction time composite	0.573 (0.076)	0.667 (0.151)	0.635 (0.121)	0.568 (0.088)
Post-concussion symptoms	5.14 (7.87)	26.18 (19.69)	13.08 (15.55)	7.18 (15.86)

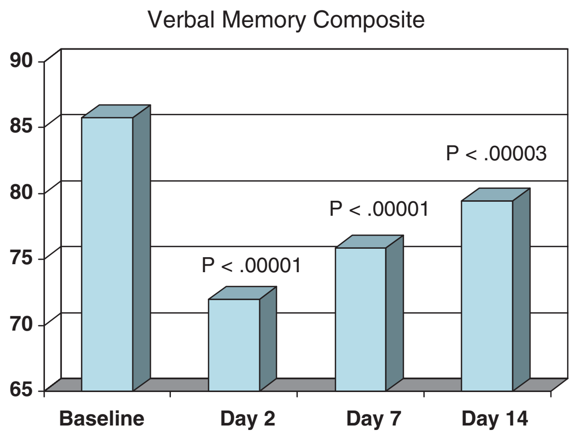

Figure 1. Mean performance on the *ImPACT* verbal memory composite for concussed samples across the four testing sessions. Scores are expressed as percentage correct. A higher score represents better performance. Pairwise comparisons are provided for each testing session. When compared to baseline performance, concussed athletes display significant deficits through day 14 testing.

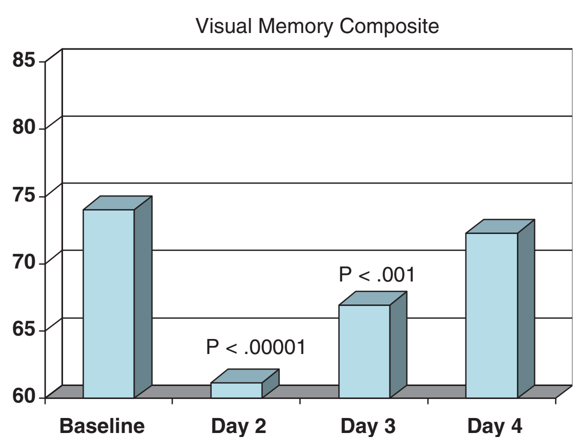

Figure 2. Mean performance on the *ImPACT* visual memory composite for concussed samples across the four testing sessions. Scores are expressed as percentage correct. A higher score represents better performance. Pairwise comparisons are provided for each testing session. When compared to baseline performance, concussed athletes display significant deficits through day 7.

comparisons (Figure 4) revealed significant differences in performance between baseline and post-injury tests at day 2 ($p < 0.01$) and day 7 ($p < 0.01$). There was no significant difference between the scores at baseline and day 14 post-injury (a lower score is better in terms of reaction time).

In terms of the symptom total score, again there was a significant difference in symptom reporting between the baseline and post-injury evaluations, $F(3,309) = 72.03$, $p < 0.01$. Specifically, significant differences were found by pairwise comparisons (Figure 5) between the baseline symptom reporting and day 2 ($p < 0.00001$) and week 1 ($p < 0.00001$) post-injury. There was no significance found

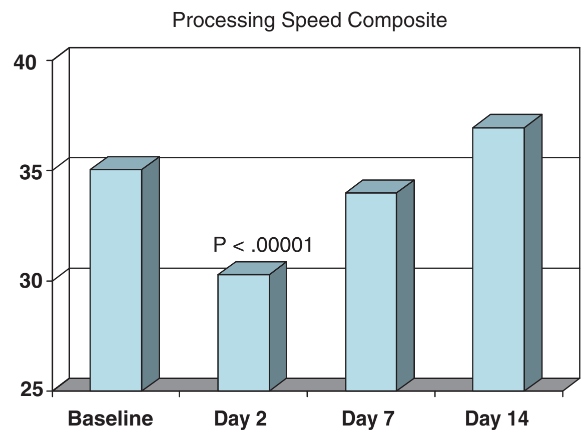

Figure 3. Mean performance on the *ImPACT* processing speed composite score. Scores are expressed in terms of average number of responses completed. A lower score is indicative of worse performance. When compared to baseline performance, the athletes showed significant deficits in functioning at 2 days post-injury.

between the baseline and third post-injury testing scores.

Discussion

In terms of neurocognitive performance, this study indicated persisting neurocognitive deficits that lasted for at least 14 days in a sample of collegiate and high school athletes. The results showed that, of the four composites, verbal memory required the longest amount of time to return to baseline levels. It showed significant deficits out to at least 14 days post injury. The other composite scores of visual memory, processing speed, reaction time and symptom reporting all showed significant differences compared to their baseline levels at days 2 and 7 post-injury. These domains did not exhibit significant deficits at day 14 post-injury, but recovery could have occurred at any point between days 8 and 14. These trends expand upon previous studies examining mild concussions in high school athletes where injured athletes still showed signs of cognitive impairment 7 days after injury [21, 22].

It is interesting to note that in this sample concussion recovery times do not appear related to concussion grade. After 1 week, three grade 1 concussions (5%) were classified as recovered and return to play was permitted. At 2 weeks post-injury, 19 had fully recovered (18.3%). The remainder of athletes maintained neurocognitive deficits or persisting symptoms past day 14. For grade 2 concussions, the recovery rate appeared to be slightly faster. Twelve had healed within 7 days (34.3%), and within 2 weeks of injury a total of 26 had returned to their sport (74%). Of the nine grade 3 concussions, one had healed within 1 week (11.1%) and four within 2 weeks (44.4%).

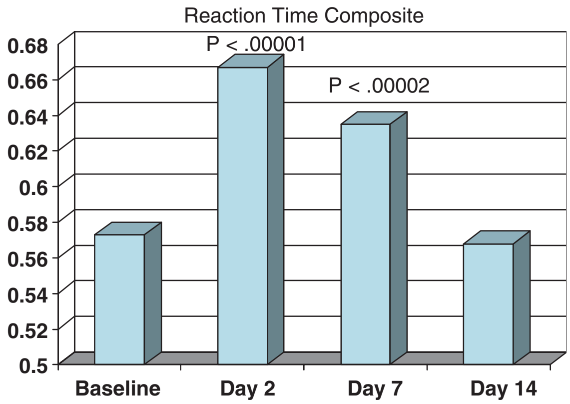

Figure 4. Mean performance on the *ImPACT* reaction time composite score. Scores are expressed in terms of average response time in seconds. A higher score is indicative of worse performance. When compared to baseline performance, concussed athletes showed deficits that persisted out to day 7 post-injury.

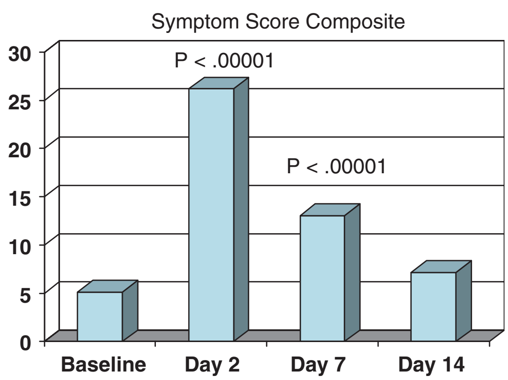

Figure 5. Mean performance on the *ImPACT* symptom composite for concussed athletes across the four testing sessions. Scores are expressed as total score on the symptom scale. A higher score is indicative of increased symptoms. When compared to baseline symptom reporting, concussed athletes demonstrate significantly higher symptoms out to day 7 post-injury.

This data suggests limitations to the guidelines set forth by the AAN and Colorado concussion grading scales. If return to play was based solely on guidelines, each player whose on-field concussion symptoms (confusion, amnesia, etc.) ameliorated within 15–20 minutes ($n = 60$) would have been returned to participation before their cognitive functioning had recovered. Only 33% of grade 2 concussions had recovered rapidly enough to permit clearance 7 days post-injury. Altogether, potentially 80% of the athletes in this sample would have returned to play prematurely if that decision had been based solely on criteria outlined in the AAN and Colorado guidelines. Further, less than 10% of the entire sample had recovered within 5 days, suggesting much longer recovery times than reported in the recently published study of concussed collegiate athletes [8].

It is also noteworthy that some cognitive deficits persisted, even after athletes were no longer reporting symptoms. Thus, cognitive deficits may remain after the injured athlete reports no overt symptoms of injury. This reaffirms the importance of neuropsychological testing in the management of concussion and return-to-play decisions following concussion, as athletes may be unaware of or unwilling to admit to the presence of concussive symptoms following injury.

The results of this study suggest that recovery from concussion may take longer than previously reported. These differences may be due to method variance in measuring cognitive changes following concussion, sample characteristics or other factors. A recent publication scrutinized the test–re-test reliabilities of many traditional paper-and-pencil neurocognitive testing measures [25]. The study detailed performance on multiple tests, including the Hopkins Verbal Learning Test, Trail Making Test, Controlled Oral Word Association Test and Digit Symbol Test. Overall, the paper-and-pencil tests were found to have an extremely low test–re-test reliability, suggestive of a possible practice effect. Consistent increases in performance over time were found in the Digit Symbol Test Trail Making Test and COWAT. The study did not find poor test–re-test reliabilities in the HVLT, but previous studies of this test have shown possible practice effects [26]. Thus, the use of computerized testing with randomized presentation of stimuli and a variety of test forms could be more sensitive in detecting subtle neurocognitive impairment at the later stages of recovery.

Although this study provides compelling evidence of protracted concussion recovery times compared to those found previously in the concussion literature, there are limitations which must be acknowledged. First, the age of the concussed sample ($M = 16.11$ years) could limit the generalizability of the findings at other levels of athletic participation. Although some collegiate athletes were included ($n = 14$) in the sample, the majority of participants competed at the high school athletic level. In a recent study, high school athletes were shown to require longer recovery times following injury than their collegiate counterparts [17, 21]. Further studies at the collegiate level would aid in both better examining recovery of collegiate athletes specifically and also further compare the recovery differences between the two levels of competition. Also, the use of clinical data is, in essence, a convenience sample which also presents limitations. Most significantly, as only patients who underwent three post-concussion testing sessions were included in this study, the sample may exhibit a longer time of recovery than their peers who were tested fewer than three times on ImPACT.

The results of this study provide important recovery time data which could impact ideas about concussion management. The fact that significant cognitive deficits were apparent up to 14 days after injury suggests that cognitive recovery following a concussive injury may take longer than previously demonstrated. In a field where injury management and return to play decisions are complex and extremely important, the knowledge that even mild injuries may show protracted recovery times is essential to making informed decisions regarding a patient's ability to return to athletic participation. Clinicians must be cognizant that recovery time from concussive injuries can significantly vary from athlete to athlete, underscoring the importance of individualized concussion management.

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