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Management and Recovery Patterns Following Sport-Related Mild Traumatic Brain Injury in Male and Female College Athletes

Kelly Knollman-Porter, Sarah Thaxton, Michael R. Hughes, and Fofi Constantinidou

Purpose: We examined patterns in mild traumatic brain injury (mTBI) management and recovery exhibited by male and female athletes over the 19-year history of a Division 1 University Concussion Management Program. **Methods:** We examined 234 diagnosed mTBIs and compared time required to return to baseline on neurocognitive and self-report symptom measures for male and female athletes. **Results:** Males and females sustained 63.3% and 36.7% of mTBI, respectively. Athletes required on average 11.89 days to return to baseline on neurocognitive assessments and 11.83 days to report being symptom-free. There was a significant difference in the number of days until genders were symptom-free, with males and females requiring on average 10.11 days and 14.30 days, respectively. **Discussion:** More collegiate athletes received pre- and post-mTBI management than in the past. There is a continued need to examine patterns of neurocognitive and symptom recovery, which may lead to earlier detection of athletes at risk for persistent post-mTBI symptoms.
Key words: *gender*, *mild traumatic brain injury*, *recovery*, *sports*, *symptoms*

A MILD TRAUMATIC BRAIN INJURY (mTBI), also referred to as a concussion, is induced by biomechanical forces resulting in complex functional disturbances rather than anatomic change (Guskiewicz et al., 2013). Collegiate athletes are specifically at risk for mTBI secondary to the competitive nature of sports. An estimated 10,560 mTBIs occur annually at the collegiate level (Zuckerman et al., 2015); however, the rate is likely higher as 21%–45% of sport-related mTBIs go unreported (Baugh, Kroshus, Daneshvar, & Stern, 2014; Kerr, Register-Mihalik, Kroshus, Baugh, & Marshall, 2016; Torres et al., 2013). The sequela of signs (e.g., physical, cognitive, neurobehavioral) and clinical symptoms (e.g., feelings of confusion) following mTBI can be short term or prolonged (McCrory et al., 2017) and negatively impact an athlete's ability to perform both on and off the field. As such, health care professions, including speech–language pathologists (SLPs) (Knollman-Porter, Constantinidou, & Hutchinson Marron, 2014), are

***Author Affiliations:** Departments of Speech Pathology and Audiology (Dr Knollman-Porter and Ms Thaxton) and Statistics (Mr Hughes), Miami University, Oxford, Ohio; and Department of Psychology and Center for Applied Neuroscience, University of Cyprus, Nicosia, Cyprus (Dr Constantinidou).*

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***Corresponding Author:** Kelly Knollman-Porter, PhD, CCC-SLP, Department of Speech Pathology and Audiology, Miami University, 301 S Patterson Ave, 2 Bachelor Hall, Oxford, OH 45056 (knollmkk@miamioh.edu).*

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responsible for managing an athlete's symptoms following injury to facilitate a safe and efficient return to previous levels of function (Kontos et al., 2018). Current research examining recovery patterns in sport-related mTBI is preliminary. In addition, the identification and management of sport-related mTBI can be challenging secondary to numerous policy, athlete, and diagnostic factors (McCrory et al., 2017). Therefore, examining mTBI management practices, occurrence rate, and athlete recovery patterns over time can provide a foundation for the development and refinement of approaches to help injured athletes return successfully to academic, social, and athletic activities.

KEY NATIONAL CHANGES IN THE MANAGEMENT OF SPORT-RELATED mTBI

The management of sport-related mTBI has evolved since the formation of the National Collegiate Athletic Association (NCAA) in 1906. At that time, the NCAA had the call to establish and reinforce safety guidelines for collegiate varsity athletics secondary to increased concerns regarding the high incidence of mTBIs and sport-related fatalities (Gravidarum, 1906; Miller, 2011; NCAA, 2018). The guidelines generated by the NCAA, at that time, marked the first nationally based effort to manage collegiate sport-related mTBI.

Many decades later, in 1982, the NCAA created the Injury Surveillance System (ISS) to gather data regarding the incidences of injuries in collegiate athletes. This resulted in the refinement of safety policies for some (e.g., ice hockey, football, lacrosse) but not all (e.g., baseball, wrestling) sports (Dick, Agel, & Marshall, 2007). In one of the first longitudinal studies using data from the ISS involving multiple sports, Hootman, Dick, and Agel (2007) found that mTBI frequencies had doubled from the academic years of 1988–1989 to 2003–2004, revealing the need for better management of sport-related head injuries and continued development of prevention interventions (Van Mechelen, Hlobil, & Kemper, 1992).

As a result of the ISS outcomes, in 2010 the NCAA released an overarching mandate requiring that all member schools have a concussion management program in place that included at least the following four components: (1) athletes will be provided education annually regarding the signs and symptoms of mTBI and will acknowledge their responsibility to report a suspected mTBI; (2) athletes with a suspected mTBI will be removed from play and evaluated by a medical professional; (3) athletes diagnosed with a mTBI are not permitted to return to practices or games for at least 1 day; and, (4) athletes diagnosed with an mTBI are required to obtain physician clearance before returning to play (Baugh, Kroshus, Bourlas, & Perry, 2014; NCAA, 2014). The 2010 mandate was the first set of rules that would specifically influence the management of sport-related mTBI for all athletes participating in varsity sports. Although additional best practices guidelines exist for concussion management by the NCAA, the 2010 mandate is still the only set of rules in which participating schools must follow. Compliance with this protocol is compulsory; however, the specific methods used to implement the program are at the discretion of each university's mTBI management team.

Since the implementation of the NCAA mandate, a more recent examination by the Injury Surveillance Program revealed that among 25 sports, the overall mTBI rate between 2009 and 2014 increased to 4.47 per 10,000 athlete exposures, with the largest annual estimates occurring in men's football, women's soccer, and women's basketball (Zuckerman et al., 2015). However, ultimately, it is unknown whether this increase in mTBI rate is secondary to improved injury identification and reporting or actual frequency of injury.

CHALLENGES ASSOCIATED WITH THE IDENTIFICATION AND MANAGEMENT OF SPORT-RELATED mTBI

Sport-related mTBI is considered one of the most challenging injuries to assess and manage secondary to the rapidly evolving and often invisible clinical symptoms, physical signs, cognitive changes, neurobehavioral features, and sleep–wake disturbances uniquely experienced by each athlete following injury (McCrory et al., 2017). Many of the symptoms experienced post-mTBI are not easily identified by medical professionals unless self-reported by the athlete (Cantu, Guskiewicz, & Register-Mihali, 2010; Williams, Puetz, Giza, & Broglio, 2015). However, many athletes resist reporting a suspected injury due to a desire to play, maintain their current position, and meet the expectations of coaches, teammates, and parents (Davies & Bird, 2015; Kroshus, Garnett, Hawrilenko, Baugh, & Calzo, 2015). In addition, many athletes also demonstrate incomplete knowledge of the signs and symptoms of mTBI (Fedor & Gunstad, 2015; Harmon et al., 2013; Knollman-Porter, Brown, & Flynn, 2018) and therefore fail to self-report because they perceive that the injury was not severe enough, associate the symptoms experienced with other injuries or illnesses (e.g., dehydration, physical fatigue, cold, migraine), and/or feel that their personal previous experience with an mTBI leads to accurate knowledge and expectations of recovery (Knollman-Porter & Brown, 2018). These factors, alone and combined, can result in an athlete returning to play prior to recovery, increasing the risk of sustaining a second injury and experiencing greater and more persistent postinjury symptoms (Harmon et al., 2013).

POSTINJURY ASSESSMENT AND RECOVERY PATTERNS

Currently, there is no single gold standard method of assessment to determine when and whether an athlete recovers from mTBI (McCrory et al., 2017). Because of the complex nature of mTBIs, best practice suggests that a multidisciplinary team (e.g., physician, athletic trainer, SLP, physical therapist, neuropsychologist) utilize multiple methods unique to each discipline's specialty area (e.g., vestibular, oculomotor, neurocognitive) to identify and manage the sequelae of a sport-related injury (Kontos et al., 2018; McCrory et al., 2017). For the purposes of this article, the authors will primarily focus on the postinjury neurocognitive performance and self-report symptom changes (e.g., somatic, cognitive, emotional) experienced by athletes and often managed by SLPs (Hardin & Kelly, 2019; Knollman-Porter, Constantinidou, Beardslee, & Dailey, 2019).

Assessment of symptoms through self-report is the most commonly utilized technique in mTBI management (Dessy et al., 2017) as it is often the first method to detect whether an athlete is experiencing change postinjury (Aubry et al., 2002). Furthermore, professionals use self-report measures on the sideline and/or during recovery not only to document immediate (Brett et al., 2018; Merritt, Rabinowitz, & Arnett, 2015) and delayed symptom onset (Duhaime et al., 2012) but also for continued monitoring over the course of recovery (Dessy et al., 2017; Harmon et al., 2013; Littleton & Guskiewicz, 2013; Lovell et al., 2006). Collection of symptom-related data provides rehabilitation professionals with valuable information, which may dictate recommendations for academic accommodations and supportive strategies (Harmon et al., 2013; McCrory et al., 2013).

The inherent subjectivity of self-report measures is a concern, as it may result in potential bias by inaccurate or absent athlete reports (Meier et al., 2015). This issue, combined with the low sensitivity and specificity rates (Lau, Collins, & Lovell, 2011), suggests that self-report measures should not be the sole method used to determine change or recovery. Computer-based neurocognitive assessments are widely utilized across Division 1 universities (Kerr et al., 2015) as they are quick, simple to administer, and assess a variety of neurocognitive components (e.g., attention, memory) both on and off the field. Although it is possible to compare post-mTBI neurocognitive results with age and gender-based norms, the effectiveness of such tests is enhanced with preinjury baseline data due to the athlete's unique preinjury cognitive status. Collection of baseline neurocognitive and symptom data provides an estimate of preinjury cognitive function, which can be used as an initial step to determine mTBI recovery and potential readiness to return to play (McCrory et al., 2013; Nakayama, Covassin, Schatz, Nogle, & Kovan, 2014; Ravdin, Barr, Jordan, Lathan, & Relkin, 2003; Schatz, Pardini, Lovell, Collins, & Poddell, 2006). Although the sensitivity and specificity rates of neurocognitive measures are high, some mTBIs still go undetected (Dessy et al., 2017; Giza et al., 2013; Harmon et al., 2013). However, combining neurocognitive measures with self-report symptom measures improves the clinician's ability to identify change postinjury over either measure used in isolation (Alsalaheen, Stockdale, Pechumer, & Broglio, 2016; Broglio, Macciocchi, & Ferrara, 2007; Dessy et al., 2017), leading to more effective management and safer return-to-play decisions (Giza et al., 2013; Kerr et al., 2015).

An athlete's performance on neurocognitive assessment and symptom-report measures do not consistently return to baseline levels simultaneously following mTBI, with some athletes returning to baseline on neurocognitive assessments before reporting being symptom-free (Teel, Marshall, Shankar, McCrea, & Guskiewicz, 2017; Williams et al., 2015). Symptom recovery time has steadily increased, possibly due to increased educational mandates and media attention regarding the signs and symptoms of mTBI (Wasserman, Kerr, Zuckerman, & Covassin, 2016). More specifically, Wasserman et al. (2016) found that between 2009 and 2014, the proportion of sport-related mTBI with prolonged symptom resolution time increased with a significant linear trend. However, at least 15% of athletes diagnosed with mTBI experience persistent changes in neurocognitive performance and/or postinjury symptoms, which do not resolve within a week and can interfere with academic and sport responsibilities (Bernstein, 1999; Macleod, 2010).

Current estimates suggest that collegiate athletes typically return to baseline levels of performance and report being symptom-free within 10–14 days postinjury on average (McCrory et al., 2017). However, caution should be used when reviewing recovery estimates. More specifically, a systematic review of return-to-play following sport-related mTBI concluded that the current evidence on recovery patterns is preliminary and that more evidence is needed to determine factors that may or may not truly influence recovery (Cancelliere et al., 2014; Wasserman et al., 2016). Possible factors affecting return to previous levels of function include the severity and location of the injury (Crisco et al., 2010), previous history of mTBI (Covassin, Stearne, & Elbin, 2008), athletes with a higher number and duration of postinjury symptoms (Cancelliere et al., 2014), and/or female gender (Kutcher & Eckner, 2010).

Gender differences

Approximately 56 % of collegiate athletes are male and 44 % are female (NCAA, 2018). Different rates of mTBI and patterns of recovery can occur between these groups. Specifically, in gender-comparable sports (e.g., soccer and basketball), females had a 1.4 times greater incidence of sport-related mTBI than males (Covassin, Mora, & Elbin, 2016). However, time loss from sport participation following injury can be more variable. Specifically, female soccer players required approximately 3 more days than males to return to play following an mTBI sustained during practice, but there was no difference when the injury occurred during competition (Covassin et al., 2016). In contrast, the opposite was found between male and female basketball players (Covassin et al., 2016).

Athletes self-report an average of five to seven symptoms (Wasserman et al., 2016) that vary in type and severity on the basis of the location and degree of the head impact (Harmon et al., 2013; McCrea et al., 2013; Teel et al., 2017). The symptoms most frequently reported post-mTBI include headache, dizziness, and difficulty concentrating (Currie, Kraeutler, Schrock, McCarthy, & Comstock, 2017; Marar, McIlvain, Fields, & Comstock 2012; Wasserman et al., 2016). Some preliminary evidence also suggests that reporting patterns differ between genders, with males reporting more instances of amnesia and confusion and females reporting more cases of drowsiness, sensitivity to light (Frommer et al., 2011) and fatigue (Covassin et al., 2016). In addition, there is evidence suggesting that females report more overall symptoms (Covassin, Elbin, Bleecker, Lipchik, & Kontos, 2013) and exhibit greater postinjury declines with visual memory, reaction time, and executive function on neurocognitive assessments than males (Broshek et al., 2005; Colvin et al., 2009; Covassin et al., 2013). In contrast, however, Wasserman et al. (2016) found no significant difference in the average number of symptoms and symptom resolution time between genders. With more females participating in collegiate athletics than in previous decades, there is a need for continued research examining recovery patterns between genders.

Statement of the problem

Currently, more than 480,000 male and female collegiate athletes compete in NCAA-sponsored sports annually (NCAA, 2018). Because of the nature of competitive sports, all of these athletes are at risk of sustaining mTBI. Over the course of the past two decades, medical professions, including SLP, have worked to more effectively and efficiently manage and understand the variable and often complex postinjury signs and symptoms of mTBI. Although the effects of brain injury can impact individual athletes in different ways, examination of trends in preinjury management protocols, such as neurocognitive baseline testing, injury occurrence rates, and patterns of recovery over the past two decades, may reveal successes, along with areas where continued improvement is warranted, such as the need for better education and postinjury care. Therefore, the purpose of this study was to examine changes in frequencies of preinjury baseline neurocognitive testing, mTBI rates, and neurocognitive and symptom recovery patterns exhibited by male and female athletes participating in varsity sports over the 19-year history of a Division 1 University Concussion Management Program. We addressed the following research questions:

- What changes occurred in the frequency of baseline testing and sport-related mTBI rates at a Division 1 university over the 19-year history of the Concussion Management Program?
- What are the differences in recovery patterns exhibited between athletes who return to baseline on neurocognitive assessment measures and report being symptom-free and athletes who experience persistent changes following sport-related mTBI?
- What are the differences in recovery patterns between males and females on neurocognitive assessment results and self-reported symptoms measures following a sport-related mTBI?
- What are the differences in recovery patterns between males and females on neurocognitive assessment results and self-reported symptoms measures pre- and postimplementation of the 2010 NCAA mandate?

METHODS

Study design

The authors implemented a prospective cohort study examining the demographic data, baseline, and post-mTBI neurocognitive testing results and self-rated postinjury symptom scores of male and female collegiate athletes referred to a Midwestern Division 1 University Concussion Management Program by athletic trainers or physicians between 1999 and 2018. The Concussion Management Program is a collaboration between a university-based speech–language pathology program and intercollegiate athletics. The program provides a multidisciplinary team approach (e.g., team physician, athletic trainers, SLP, student athlete) to the assessment, diagnosis, management, and prevention of the neurocognitive and physical sequelae resulting from sport-related mTBIs.

Selection of mTBI data for analysis

Recruitment of potential participants occurred prior to the start of the athletic season during required baseline neurocognitive testing sessions and prior to injury. If interested in study participation, athletes completed informed consent procedures for permission to include all baseline and postinjury testing results in a secure, de-identified database for later analysis. The institutional review board approved the procedures for participant recruitment and informed consent.

At the time of data analysis, there were 286 incidences of diagnosed mTBI sustained by 256 athletes within the 19-year-old database. Only diagnosed mTBIs sustained by collegiate athletes older than 18 years with documented completion of baseline neurocognitive testing were included in the analysis. Diagnostic criteria included a self-report of physical, cognitive, or behavioral/emotional symptoms typical of mTBI and/or demonstration of a decline from baseline scores greater than 1 standard deviation on a single neurocognitive measure (Knollman-Porter et al., 2014). We excluded 52 documented mTBIs from the analysis secondary to 50 of the injuries occurring prior to baseline testing completion and two not meeting the age criteria, resulting in 234 mTBIs sustained by 226 athletes in the final analysis. Of these athletes, six sustained multiple mTBIs during their time participating in college athletics.

Materials

During the 19-year history of the Concussion Management Program, testing materials changed as technology and efficiency of methods to assess subtle neurocognitive changes experienced by athletes improved. Therefore, the authors analyzed data from the neurocognitive assessments most consistently implemented during the history of the program by speech–language pathology, which included (a) Post-Concussion Symptom Scale (PCSS; Lovell & Collins, 1998), (b) Controlled Oral Word Association Test (COWAT; Benton & Hansher, 1978), (c) Grooved Pegboard Test (GPT; Klove, 1963), and (d) Immediate Post-Concussion Assessment and Cognitive Test (ImPACT; ImPACT Applications Inc., 2016). Of these assessments, the authors utilized the PCSS, COWAT, and the GPT throughout the duration of the program and used ImPACT for 14 of the 19 years after its introduction in 2005.

Post-Concussion Symptom Scale

The PCSS (Lovell & Collins, 1998) provides a standardized procedure to document the subjective physiologic, cognitive, and emotional symptoms an athlete may experience following mTBI. The PCSS utilizes common terms easily understood by athletes (Schatz et al., 2006) and includes a wide variety of symptoms that are often less recognized postinjury, such as sadness (Currie et al., 2017). The rating scale consists of 21 symptoms and a 7-point Likert scale with scores from 0 (e.g., symptom not present) to 6 (e.g., symptom is severe) for each symptom. Some researchers suggest that the PCSS is more sensitive than neurocognitive measures in identifying mTBIs less than 1 week from the initial injury (Alsalaheen, Stockdale, Pechumer, Broglio, & Marchetti, 2017).

Controlled Oral Word Association Test

The COWAT is a nationally normed test used to assess word fluency, word retrieval, and executive function (e.g., generative thinking and thought flexibility) from which a total score is calculated and adjusted for gender and completed years of education (Benton & Hansher, 1978). Specifically, the athlete makes verbal association to different letters of the alphabet by saying all the words that he or she can think of beginning with a given letter within 1 min. Three letters of progressively increasing difficulty are presented. The COWAT has high test–retest reliability when using the total word score (Barr, 2001; Ross et al., 2007), which is the score analyzed in this study.

Grooved Pegboard Test

The GPT assesses fine motor speed and control, producing a mean score that takes gender and age into consideration (Klove, 1963).

The pegboard utilized contains 25 holes with randomly positioned slots. Twenty-five individual pegs, which have a key on one side, are inserted into the hole. Athletes then place each peg into the hole as quickly as possible, first using their dominant hand without using their nondominant hand. The athletes repeat this procedure using their nondominant hand. Test administrators sum the total time, in seconds, required to complete the task with the number of peg drops and the number of placed pegs for each hand. Previous research has found the GPT to be sensitive in identifying decline following mTBI (Constantinidou & Zimmerman, 2005). In their systematic review of available literature, Causby, Reed, McDonnell, and Hillier (2014) compared multiple fine-motor tests and found the GPT to have a moderate to strong effect size and good validity and reliability compared with like-tests in the evaluation of psychomotor skills.

Immediate Post-Concussion Assessment and Cognitive Test (ImPACT)

ImPACT is a computer-based assessment containing demographic information, neurocognitive testing, and pre- and postsymptoms ratings sections. The demographic section contains information on sport, medical, education, and mTBI history. The program also includes a section where athletes can self-rate any symptoms they may be experiencing associated with mTBI pre- and post-neurocognitive testing. By using this method, test administrators can determine whether cognitively strenuous activity exacerbates any postinjury symptoms experienced by the injured athlete. There are seven neurocognitive subtests, which target different domains of cognitive functioning, including attention, memory, processing speed, and reaction time. The computer program generates five separate composite scores from these seven subtests that include verbal memory, visual memory, visuomotor processing speed, reaction time, and impulse control (Majerske et al., 2008).

ImPACT's neurocognitive components exhibit greater sensitivity at detecting cognitive change following mTBI when compared with other computer-based neurocognitive testing methods and are most sensitive 1–3 weeks postinjury (Alsalaheen et al., 2017; Schatz et al., 2006). The creators of ImPACT combined objective neurocognitive testing and athletes' subjective self-report of postinjury symptoms to enhance the sensitivity of the battery. Specifically, there was a significant correlation between symptom reporting and decreased performance on ImPACT Reaction Time, Verbal Memory, and Processing Speed Indices (Iverson, Gaetz, Lovell, & Collins, 2004). Schatz et al. (2006) found that the combined sensitivity of ImPACT and symptom rating is 81.9% and the specificity is 89.4%.

Procedures

Trained graduate students in speech–language pathology implemented baseline and postinjury testing to athletes individually in a quiet, distraction-free environment while under the supervision of a certified SLP. The students monitored each athlete during testing and documented any observed postinjury symptoms, signs of test confusion (e.g., staring at the instructions for a prolonged period of time), or behaviors suggesting that the athlete was purposely sandbagging results (e.g., looking at phone during testing). In addition, the first author reviewed all baseline test results following completion. If suboptimal performance was suspected, the athlete was required to retake a different version of the test on a different day. Test administrators implemented the following assessments, which were previously discussed, to obtain a baseline level of neurocognitive performance for each athlete prior to the start of the athletic season: PCSS, COWAT, GPT, and ImPACT (Knollman-Porter et al., 2014).

Postinjury assessment

Physicians and athletic trainers referred athletes to the Concussion Management Program for postinjury testing following a suspected mTBI. Test administrators then implemented the same tests completed during baseline assessment, with alternative assessment forms for the COWAT and ImPACT to avoid a practice effect (Knollman-Porter et al., 2014). To determine whether the testing procedure heightened postinjury symptoms, athletes also completed the PCSS for a second time following test completion. Scores greater than 1 standard deviation below baseline performance on a single post-mTBI assessment and/or an athlete's self-report of symptoms on the PCSS indicated neurocognitive change suggestive of mTBI.

Return to baseline and symptom-free

Data collection of this method occurred on a weekly basis or as needed, until performance on all neurocognitive measures returned to baseline levels and the athlete reported experiencing no symptoms on the PCSS. Once the athlete met both of these criteria, no further testing was recommended unless the athlete's symptoms returned with increased physical or academic exertion.

Persistent changes

The athlete's physician made all return-to-play decisions. In some instances, the physician approved return-to-play and termination of subsequent testing prior to the athlete being symptom-free or returning to baseline levels of neurocognitive performance. This occurred when the physician determined, based on the athlete's medical history, that prolonged recovery was secondary to physical (e.g., cervicogenic headache) or psychologic (e.g., depression) factors. In other situations, the athlete failed to return for recommended testing (e.g., recreational collegiate athletes) or decided to terminate athletic participation prior to his or her symptoms and neurocognitive scores returning to baseline.

Trained graduate research assistants deidentified, coded, and entered all demographic data, neurocognitive testing results, and symptom self-rating scores into a digital database. To assess the reliability of data entry, a blind reviewer randomly selected and checked 10% of all data entered into the mTBI database. This yielded an error rate of less than 1%.

Data analysis

The authors used descriptive statistics to describe the trends in baseline testing and mTBI rate, examining patterns based on gender, age, and grade level. The authors then divided the data set into two groups for analysis. The first group included athletes who returned to baseline on all neurocognitive testing measures (COWAT, GPT, and ImPACT) and reported being symptom-free on the PCSS. The second group included athletes who demonstrated persistent changes when compared with baseline. These athletes failed to return to baseline measures on one or more neurocognitive assessments and/or continued to report symptoms on the PCSS and were either cleared by the physician to return to play or did not return for further testing. Within each of these groups, the authors first analyzed neurocognitive testing and symptom-reporting patterns based on gender.

We presented all numeric descriptive statistics as means and standard deviations. Chi-square tests of association were used to determine whether the data exhibited a significant first-recovery pattern in neurocognitive measures versus symptom recovery by gender. More specifically, we determined whether male or female athletes first return to baseline levels of performance on neurocognitive measures or report being symptom-free first. To compare the distribution of recovery time by gender, we utilized a nonparametric Wilcoxon rank sum test to account for the positively skewed responses.

We then incorporated time effects into the gender comparison for the return to baseline and symptom-free group. Because of the strong influence of the 2010 NCAA mandate on mTBI management practices, we compared the following three time frames: 1999–2008 (pre-NCAA guidelines), 2009–2013 (onset of new NCAA guidelines), and 2014–2018 (post-NCAA guidelines). Two-way analyses of variance were then performed on each of the recovery time responses ([1] days until neurocognitive deficit-free; [2] days until symptom-free, and [3] difference in days to recover between neurocognitive deficits and symptoms). The factors were gender (two levels: male, female) and year (three levels: 1999–2008, 2009–2013, and 2014–2018). Responses were log transformed to correct skewness. All statistical tests were performed at the 5% significance level. The authors utilized SAS/STAT software Version 14.2 of the SAS System for windows to complete all data analysis (SAS Institute, Inc., 2013).

RESULTS

Baseline and post-mTBI testing trends

Over the 19-year history of the Concussion Management Program, athletes completed approximately 1,565 baselines tests. During the early years of the program, athletes on the varsity football, ice hockey, men's and women's basketball, and women's soccer and softball teams received neurocognitive baseline testing prior to the onset of preseason training. Specifically, between 1999 and 2008, the number of baseline tests completed per year ranged from 46 to 85 (M = 63.11; SD = 14.48). In contrast, in 2009, in anticipation of the onset of the 2010 NCAA guidelines mandating that universities implement a protocol to manage the sequelae of sport-related mTBI, athletes from varsity baseball, field hockey, diving, and track and field (e.g., pole vaulters) began receiving baseline testing. More recently included in baseline testing are the athletes in sports such as synchronized skating and cheerleading. Between 2009 and 2018, the number of athletes receiving baseline testing per year increased ranging from 89 to 153 (M = 117.44, SD = 24.47).

To date, 286 athletes received postinjury testing secondary to sustaining a suspected mTBI since the start of the program in 1999. Over the study period with available data regarding total athlete participation per year in varsity athletics (2000–2018), there was a significant increasing linear trend in the rate of mTBI (b = 0.132 additional mTBIs per 100 athletes per year, SE = 0.034, p = .0014). Table 1 contains the rate of mTBI per year per 100 athletes.

Demographic analysis

Frequency of mTBI by gender, age, and education

The average number of athletes participating in varsity collegiate athletics per year was 555.35 (SD = 13.64) with an average 299.00 male (SD = 10.00) and 256.35 females (SD = 9.54) participating per year. Of the 234 diagnosed mTBIs included in the analysis, males and females sustained 63.3% (n = 148) and 36.7% (n = 86) of mTBIs, respectively. The average age of athletes at the time of mTBIs was 19.69 years (range = 18–23 years, SD = 1.36) with the peak percentage of

Table 1. Rate of mTBIs per 100 athletes per year: 2000–2018

Year	Number of Varsity Athletes per Year	Rate of mTBI per 100 Athletes
2000–2001[a]	502	1.39
2001–2002[a]	551	3.44
2002–2003[a]	545	1.83
2003–2004[a]	515	0.97
2004–2005	472	2.33
2005–2006	547	2.19
2006–2007	528	3.22
2007–2008	544	2.02
2008–2009	552	1.81
2009–2010[b]	546	2.74
2010–2011	543	3.31
2011–2012	566	2.65
2012–2013	554	3.61
2013–2014	560	4.10
2014–2015	566	4.40
2015–2016	569	3.69
2016–2017	554	4.33
2017–2018	564	2.83

Note. mTBI = mild traumatic brain injury.
[a]Data from a historic file which predates current student information system.
[b]Onset of National Collegiate Athletic Association 2010 mandate.

injuries (31.33%) occurring in athletes 19 years of age. Rates declined as age increased, with the lowest percentage occurring in 22 (6.87%) and 23 (3%)-year-olds (see Table 2).

The average amount of education completed at the time of the injury was 13.28 years (range = 11–16 years; $SD = 1.05$), with freshmen athletes sustaining the greatest percentage (32.55%) of recorded mTBIs ($n = 69$). Mild traumatic brain injury rates steadily decreased with sophomores sustaining 30.19% ($n = 64$), juniors sustaining 24.06% ($n = 51$), seniors sustaining 12.74% ($n = 27$), and fifth-year seniors sustaining the least amount of mTBIs at 0.47% ($n = 1$).

Post-mTBI symptom patterns of occurrence

Of the 234 mTBIs diagnosed, athletes reported experiencing a wide variety of postinjury symptoms with the five most prevalent being headache (77%), difficulty concentrating (64%), drowsiness (60%), feeling mentally foggy (59%), and fatigue (59%). When examining differences between genders, males most often experienced headache (73%), feeling mentally foggy (62%), difficulty concentrating (62%), drowsiness (59%), and fatigue (57%). Similarly, females reported the highest incidence of headache (84%), followed by difficulty concentrating (67%), drowsiness (63%), fatigue (63%), and noise sensitivity (58%) (see Table 3).

Neurocognitive and symptom recovery patterns

For the purposes of this analysis, we will first reveal the recovery patterns of athletes who returned to baseline on neurocognitive assessments and reported being symptom-free following mTBI. Within this group, the authors examined differences in recovery patterns between genders and over key points in time. This discussion is followed by a review of the patterns exhibited by athletes with persistent changes postinjury. As part of our protocol since 1999, all athletes are given the opportunity to receive individualized academic accommodations if they experience post-mTBI neurocognitive change of symptoms.

Return to baseline and symptom-free group

Of the 234 diagnosed mTBI analyzed, 68.37% ($n = 160$) returned to baseline levels of neurocognitive performance on all assessment measures and reported being symptom-free.

On average, athletes in the return-to-baseline and symptom-free group required 11.89 days ($SD = 12.18$) to return to baseline levels of function on all neurocognitive assessments and 11.83 days ($SD = 11.81$) to report being symptom-free. There was no significant difference in the proportions examined ($\chi^2 = 0.1268$, $df = 1$, $p = .7218$), with 47.89% of athletes returning to baseline on neurocognitive assessment first and 52.11% reporting being symptom-free first.

Overall gender-specific recovery patterns

The authors used the χ^2 tests of association to determine whether return to baseline and symptom-free males and females returned to baseline on neurocognitive assessments first, reported being symptom-free first, or returned to baseline on both at the same time of testing. Although the majority of athletes returned to baseline on both

Table 2. Age of athletes at the time of mild traumatic brain injury

	18 Years	19 Years	20 Years	21 Years	22 Years	23 Years
$n =$	43	73	52	40	16	7
Percentage	18.45	31.33	22.32	17.17	6.87	3

Table 3. Reported symptoms

Gender					
Male (n = 148)		**Female (n = 86)**		**Overall (n = 243)**	
Symptom	***n***	**Symptom**	***n***	**Symptom**	***n***
Headache	108	Headache	72	Headache	180
Foggy	93	Diff C	58	Diff C	149
Diff C	91	Drowsy	54	Drowsy	141
Drowsy	87	Fatigue	54	Foggy	139
Fatigue	84	S noise	50	Fatigue	138
S Light	79	Dizzy	46	S Light	124
Dizzy	76	Slow	46	Dizzy	122
Slow	76	Foggy	46	Slow	122
S Noise	66	S Light	45	S noise	116
Diff R	59	More sleep	40	More sleep	93
More sleep	53	TFS	33	TFS	85
TFS	52	Balance	32	Diff R	84
Irritable	50	Irritable	29	Irritable	79
Nausea	44	FME	28	Balance	76
Balance	44	Sadness	26	Nausea	68
Less sleep	43	Diff R	25	Less sleep	61
FME	32	Nausea	24	FME	60
Visual[a]	32	Nervousness	21	Sadness	54
Nervousness	28	Less sleep	18	Visual	50[a]
Sadness	28	Visual	18[a]	Nervousness	49
Numbness	24	Numbness	12	Numbness	36
Vomit	5	Vomit	0	Vomit	5

Note. Balance = balance problems; Diff C = difficulty concentrating; Diff R = difficulty remembering; FME = feel more emotional; Foggy = mentally foggy; Irritable = irritability; Less sleep = sleep less than usual; More sleep = sleep more than usual; S Light = sensitivity to light; slow = feeling slowed down; S Noise = sensitivity to noise; TFS = trouble falling asleep; Visual = visual problems.

[a]Visual problems was not included on paper-based Post-Concussion Symptom Scale.

neurocognitive and symptom measures at the same time, the χ^2 analysis revealed that recovery patterns differed significantly between males and females ($\chi^2 = 5.05$, $df = 2$, $p = .0079$). Specifically, more males reported being symptom-free first and more females returned to baseline on neurocognitive assessments first (see Table 4).

Days until return to baseline on neurocognitive assessments and symptom-free

A Wilcoxon rank sum test revealed no significant difference ($z = 1.23$, $p = .2179$) in number of days required to return to baseline on neurocognitive assessments between males ($M = 10.96$, $SD = 11.07$) and females ($M = 13.18$, $SD = 13.58$). In contrast, analysis revealed a significant difference ($z = 2.83$, $p = .0045$) between males and females in number of days until symptom-free, with males requiring an average of 10.11 days ($SD = 10.11$) and females requiring 14.30 days ($SD = 13.58$). A formal analysis conducted using the differences in recovery times on neurocognitive assessment and symptom reporting revealed a statistically significant discrepancy between genders ($z = 2.17$, $p = .0296$). Specifically,

Table 4. First recovery patterns by gender

	Recovered First From:				
	Equal	**Neurocognitive**	**Symptoms**	**Total**	χ^2 (*p*)
Gender					
Male	53 (56.4%)	15 (16.0%)	26 (27.6%)	94	**5.05 (.0079)**[a]
Female	36 (54.5%)	19 (28.8%)	11 (16.7%)	66	

[a]Values in boldface are significant at $p < .05$.

males reported being symptom-free 0.73 days faster than the time required to return to baseline on neurocognitive assessment. However, females returned to baseline on neurocognitive assessments 1.02 days faster than self-reports of being symptom-free.

Gender-specific recovery patterns by time

For all three time frames (1999–2008 [$n = 22$], 2009–2013 [$n = 58$], and 2014–2018 [$n = 74$]), there was no significant interaction between year and gender (neurocognitive deficit-free: $p = .9861$, symptom-free: $p = .6324$, difference in days to recover between neurocognitive deficits and symptoms: $p = .9413$). Furthermore, there were no significant changes in any of the three responses over time. Gender was significant only with respect to days until symptom-free, with males having significantly shorter symptom mean recovery time ($p = .0204$) regardless of year.

Persistent changes group

Of the 234 diagnosed mTBIs included in the analysis, 31.62% ($n = 74$) of athletes exhibited persistent changes. Of this group, five of these athletes demonstrated one unresolved neurocognitive assessment score below baseline, 65 reported at least one persistent symptom, and four exhibited a co-occurring persistence in both neurocognitive and symptom performance at the time testing was terminated by either the physician or the athlete. Because of these missing data, formal analysis of recovery patterns between genders could not be performed. However, for these data, nearly 90% of all mTBIs sustained indicated that the persistent changes athlete returned to baseline on neurocognitive assessments more frequently than being symptom-free. The five most common symptoms reported by persistent changes athletes, at the time of testing termination, included headache ($n = 40$), fatigue ($n = 32$), difficulty concentrating ($n = 30$), mental fogginess ($n = 27$), and drowsiness ($n = 25$). The subtests in which the nine persistent changes athletes exhibited continued deviations from baseline on neurocognitive measures included visuomotor speed ($n = 4$), visual memory ($n = 2$), verbal memory ($n = 2$), and reaction time ($n = 1$). None of these athletes' scores deviated from baseline on more than one subtest.

DISCUSSION

Within the last decade, the NCAA mandated that all university-based athletic programs implement an mTBI management protocol that includes annual education and return-to-play guidelines for all athletes (NCAA, 2010). Although this legislation has the potential to improve the care of athletes pre- and postinjury, the aim of the current study was to analyze patterns of mTBI management and recovery over the 19-year history of a Division 1 University Concussion Management Program. Within this analysis, we examined the patterns of recovery exhibited by male and female athletes participating in varsity sports. In the following sections, we discuss the implications of our findings and potential future research directions.

Longitudinal trends in mTBI management

Examination of baseline test completion and mTBI rates over the past 20 years reveals positive patterns in the management of collegiate sport-related mTBI. Specifically, at the start of our Concussion Management Program in 1999, prior to the 2010 NCAA mandates, athletes from six varsity sports received preseason baseline testing. At the time of data analysis, this number doubled with athletes from 13 varsity sports now receiving preseason testing. These findings have positive clinical implications because comparison of postinjury neurocognitive test scores to baseline data are more sensitive at detecting the subtle neurocognitive effects of sport-related mTBI than when compared with national norms (McCrory et al., 2013; Schatz et al., 2006). In addition, because approximately 45% of athletes relay not reporting a suspected mTBI to a coach or medical professional (Davies & Bird, 2015), comparisons of postinjury data to neurocognitive testing baseline data may identify an mTBI even when athletes fail to reveal postinjury symptoms (Alsalaheen et al., 2017).

Another trend observed from the analysis was a significant increasing linear trend in diagnosed sport-related mTBIs since the onset of the program. However, interpretation of these results is less clear secondary to numerous factors that could influence these findings. One potential factor for this increase is a greater number of athletes included in the analysis over time secondary to six new sport teams participating in the management program since the onset of the program in 1999.

In contrast, collegiate varsity sports are becoming more aggressive secondary to substantial increases in the height, weight, and body mass index of college athletes (Yamamoto, Yamamoto, Yamamoto, & Yamamoto, 2008). Increases in athlete size often suggest more muscle and strength for the demands of the sport, hence increasing an athlete's risk for sustaining an mTBI. Finally, the increase in mTBI rate could be secondary to greater injury identification by medical personnel. For example, many collegiate programs now have a team of professionals (e.g., physicians, athletic trainers, SLPs, neuropsychologists, and physical therapists) working collaboratively to identify and manage the effects of sport-related-mTBI. A strength of this collaboration is that each member brings to the team a unique skill set, facilitating earlier injury detection for athletes with more subtle injuries. In addition, having members of the team outside of traditional athletic environments involved in postinjury assessments may also lead to heightened symptom reporting by athletes. For example, Meier et al. (2015) determined that athletes self-reported fewer acute post-mTBI symptoms to team athletic trainers than to trained professionals in a confidential nonathletic environment. Specifically within our program, an SLP evaluates an athlete with a suspected mTBI for neurocognitive testing outside of the athletic complex. Anecdotally, over the course of the program many athletes revealed symptoms to the SLP not shared with the athletic trainer or the physician. Therefore, creating a safe testing environment, outside of the highly competitive athletic setting, may give the athletes more confidence to report symptoms associated with mTBI not previously revealed to other professionals.

Demographic variations

Consistent with previous research, males sustained almost 50% more mTBI than females at our institution. Potential factors influencing these differences could be due to more males participating in varsity collegiate sports with a greater risk of mTBI (e.g., football). However, with more women participating in high-impact sports (e.g., ice hockey) this trend may change. The data analysis also revealed that mTBI rates dropped as the grade level of the athletes increased, with more freshmen sustaining an mTBI than senior athletes. This is surprising because often times older collegiate athletes earn more playing time and starting opportunities during competitions. Because more mTBIs typically occur during competitions (Zuckerman et al., 2015), older players may have a greater risk of injury than younger players. However, with these opportunities, athletes may also experience more pressure to perform athletically even when injured. A recent study by Baugh et al. (2014) found that there was a significant difference in perceived coach support for reporting mTBI by year in school, with freshmen perceiving greater support than juniors and seniors. These findings highlight the strong influence a coach can have on the reporting practices of collegiate athletes. Similar to athletes, coaches must receive annual mTBI education. However, continued research is warranted to determine the degree to which coaches support mTBI and symptom reporting following injury among their athletes.

Immediate post-mTBI symptoms

In the current study, athletes self-reported a similar pattern of post-mTBI symptoms immediately following the injury across genders and sports. Specifically, the five most common symptoms endorsed across these groups were the physiological symptoms of headache, fatigue, and drowsiness and the neurological–cognitive symptoms of difficulty concentrating and mental fogginess. Females exhibited the only exception in reporting the neurological symptom of noise sensitivity more often than the other groups. Our findings differ in some aspects from previous research suggesting that high school males more commonly reported amnesia and confusion following mTBI whereas females reported higher rates of drowsiness and sensitivity to light (Frommer et al., 2011). Although age differences between these groups could influence postinjury symptoms, understanding the patterns of symptoms commonly experienced following injury can direct clinicians when recommending academic accommodations and supports following mTBI.

Patterns in post-mTBI recovery

As a greater number of athletes receive post-mTBI care, a more critical examination of trends in mTBI recovery patterns based on gender can occur. Historically, athletes required 7–10 days to return to baseline on all neurocognitive testing measures and be symptom-free (Giza et al., 2013; McCrea et al., 2013; McCrory et al., 2013; Wasserman et al., 2016). However, our findings suggest that athletes are taking longer to recover following mTBI. Specifically, return to baseline and symptom-free group athletes required almost 12 days to return to baseline on neurocognitive measures and report being symptom-free. Possible reasons for this increase in time could include heightened postinjury monitoring of athletes by objective professionals (e.g., SLP) outside of the athletic environment (Meier et al., 2015) or an athlete's increased willingness to reported persistent symptoms following injury. Although a reason for this change is unclear at this time, allowing athletes more time to recover following mTBI is a positive trend and may reduce risk for recurrent injury while the brain is still recovering (Harmon et al., 2013). However, if more recovery time is warranted, additional academic support and accommodations will need to be in place in order for athletes to successfully manage the fast-paced academic demands of collegiate coursework.

Gender-specific recovery patterns

An even greater difference occurred in recovery patterns between male and female athletes. Specifically, females required approximately 3 days longer to return to baseline on neurocognitive measures and 4 days longer to be symptom-free than male athletes. Our results add support to a growing body of research suggesting that female athletes recover differently from sport-related mTBIs than males (Covassin et al., 2016; Covassin, Savage, Bretzin, & Fox, 2018; Kroshus, Baugh, Stein, Austin, & Calzo, 2017). Rationale for these differences could include a greater willingness of females to report symptoms (Iverson et al., 2015), a greater risk for sustaining an mTBI secondary to differences in neck strength and body mass (Tierney et al., 2005), or the potential influence of hormonal differences between males and females (Roof & Hall, 2000).

Recovery time differences between male and female athletes in this study also suggest the necessity of using both standardized neurocognitive testing measures and symptom self-report measures when evaluating athletes following mTBI and when making return-to-activity decisions. Specifically, more males in this study became symptom-free on the PCSS first whereas more females first returned to baseline on neurocognitive measures. It is unclear whether postinjury symptoms truly resolved for the male athletes or whether they chose not to report persistent symptoms. However, because athletes traditionally have a high rate of mTBI underreporting (Register-Mihalik et al., 2013), our findings provide further support that multiple measures are needed to detect the subtle changes following injury that may go unreported (Fazio, Lovell, Pardini, & Collins, 2007).

Persistent changes following mTBI

Even with the consistent use of neurocognitive assessment and symptom measures, determining when an athlete has returned to baseline levels of performance and is appropriate to return to play following mTBI can be unclear. Often times, athletes report persistent symptoms (e.g., fatigue, drowsiness, depression, anxiety) typically experienced by college-aged adults with or without mTBI (Price, McLeod, Gleich, & Hand, 2006). Over the 19 years of this study, 31.6% of athletes demonstrated either persistent change in neurocognitive function ($n = 5$) or continued report of at least one of the 21 symptoms on the PCSS ($n = 69$). The five most common symptoms reported by the persistent changes group at the time of test termination by physician or the athlete mirrored the most common immediate symptoms (e.g., headache, fatigue, difficulty concentrating, and mental fogginess) experienced by the athletes in the return to baseline and symptom-free group. Differentiating symptom type and severity that is indicative of the general population, the athlete's past medical history versus mTBI is currently difficult. To determine cause of symptoms, the interdisciplinary team must rely on the individual to correlate changes secondary to injury rather than symptoms experienced because of daily life factors or other medical issue that may better correlate with symptoms presented, until the development of more robust methods of assessment.

Limitations and future directions

A potential study limitation is that the analysis included only data from one university-based concussion management program in the Midwest. Because of this limited scope of analysis, the information gleaned from this study may not generalize to other university programs. Therefore, evaluating other Division 1 university programs within a larger geographical area may provide greater insight into how different education and pre- and post-mTBI assessment protocols influence athlete recovery patterns over time. Other study limitations reflect the changes in mTBI management practices occurring over the 19-year span of data collection. For example, we utilized paper-based neurocognitive assessment measures at the onset of our program with computer assessments introduced in 2005. Because of this variation in materials utilized, we eliminated paper-based neurocognitive assessment data from 1999 to 2005 from our analysis and included only evaluative data consistently used throughout the majority of program. This elimination of neurocognitive assessment data limits the strength of our analysis of cognitive function and recovery patterns over time.

Finally, the accurate self-report of symptoms experienced following mTBI by an athlete, in combination with formal neurocognitive measures, can assist professionals in the identification of mTBI and when making return-to-play decisions. Although self-report measures are critical in the diagnostic process, athletes may choose to not reveal or fabricate symptoms, altering the accuracy of the results. Because of this limitation, examination of educational practices, which may facilitate accurate self-reporting patterns while taking into consideration the preferences of both male and female athletes, is warranted.

CONCLUSIONS

The examination of management practices and outcomes over time provides clinicians and researchers a medium to evaluate the strengths and limitations of past and current mTBI management practices. Over the past 19 years, a greater number of athletes within this program received education, baseline, and post-mTBI testing than in the past. Through the provision of earlier and consistent post-mTBI care, we can reduce athletes' risk of sustaining repeated injuries and hence decrease the risk of prolonged recovery. Although we are making positive changes in the management of acute mTBI, we need to examine patterns of neurocognitive and symptom recovery, which may lead to earlier detection of athletes at risk for persistent post-mTBI sequelae who may benefit from rehabilitative interventions that facilitate successful return to academic, social, and athletic activities.

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