

REVIEW ARTICLE

Trends in Recovery from Repeated Concussions in Collegiate Athletes in Collision Sports

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ABSTRACT

Sports-related concussion (SRC) is a growing concern across all age groups, particularly among collegiate athletes facing rigorous academic and athletic challenges linked to performance. For this reason, a large body of research is dedicated to this demographic. While our approach to studying concussions is more sophisticated than ever, much remains to be learned. This review addressed three specific areas of literature concerning SRC. First, does a history of concussion predispose an individual to future head injuries? Second, does the number of concussions impact time to return to play (RTP)? And third, does the interval between concussions affect the recovery trajectory? While this is not a comprehensive review, we have compiled compelling evidence that attempts to evaluate all angles of each of these three questions.

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Sports-related concussion (SRC) has emerged as a public health crisis as we become more adept with diagnosis and sports participation continues growing.¹ Sport-related concussion is a traumatic brain injury that occurs during sport play. Sport-related concussions can occur when an athlete receives a blow to the head, neck, or body that results in force to the head.² There are an estimated 1.6-3.8 million concussions across all ages in the United States annually. Of these, approximately 10,500 occur in National Collegiate Athletic Association (NCAA) athletes.³ Between 9% and 14% of collegiate athletes sustain multiple concussions during their college careers. When considering their pre-college concussion history, the number of concussions sustained by these athletes is likely under reported and underestimated.^{4,5} With such high prevalence, it is no surprise that the Consensus Statement on Concussion in Sport emphasized obtaining an in-depth concussion history before participation and during the postinjury evaluation. Despite these efforts, the Consensus Statement acknowledges that an association between a history of previous concussion and outcomes such as time to return to play (RTP) has yet to be established.⁶ Considering the unique demand placed on collegiate athletes to balance rigorous academics with athletic competition, it becomes of utmost importance to increase the understanding of potential factors contributing to, and the recovery from repeated concussions.⁷

While a return to baseline functioning is expected to occur between 2 and 7 days after a concussion for most individuals, many will suffer prolonged symptoms. Some may experience deficits in vision and memory, as well as difficulties with mood for weeks to months.⁸ In addition, there are several debilitating pathologies, such as chronic traumatic encephalopathy and dementia that have been linked to the number of years of participation in a collision sport and a history of repeated concussion. Taken together, these findings necessitate a deeper investigation of the topic to protect athletes from long-term suffering and life-threatening consequences.

Numerous reviews have sought to summarize the literature regarding concussion history and longitudinal outcomes in participants with multiple concussions. In a broad systematic review examining various factors and athletes of all ages, 41 studies were included. Of these studies, 20 found an association between a history of concussion and worse clinical outcomes following subsequent SRC. The remaining 21 found no such association.⁹ However, associations between previous concussions and longitudinal outcomes in collegiate athletes have yet to be thoroughly investigated and are an area of much-needed attention. By adding to this body of knowledge, we will be one step closer to ensuring efficacious and individualized management catered to an athlete's concussion history and to safer RTP protocols. Additionally, further elucidation of this area will hopefully stimulate more questions and future research.

Since the 1970s, clinicians began distinguishing SRC from other causes of concussion (i.e., motor vehicle crashes). This decision for separation was driven by various sporting bodies recognizing the need for clear and practical guidelines for safe RTP for

athletes with an SRC.⁶ However, until recently, the history of concussion was studied as a dichotomous risk factor: either the athlete has a history of concussion, or they do not. More nuanced approaches consider how the number of previous concussions, age of the first concussion, sex, and time between concussions impact clinical outcomes. For example, a study of collegiate athletes found that a history of three or more concussions was associated with longer recovery times, while two or fewer were not.¹⁰ This review addresses whether a history of concussion predisposes one to future concussions and if the number of previous concussions affects the RTP time in SRC for collegiate athletes. Additionally, we will address whether the time between head injuries influences the recovery trajectory. Factors we will consider are the age of the first concussion, sex, sport played, and the number of concussions sustained. The breadth and complexity of this topic limits our ability to conduct a comprehensive review, but we attempt to raise points for future investigation. This will in turn help with patient/student athlete care and welfare.

GRAND CONSORTIUM NCAA/DOD

The NCAA/U.S. Department of Defense (DoD) Grand Alliance concussion assessment research and education (CARE) consortium was formed in 2014 to "inform science, clinical care and public policy related to concussion and repetitive head impact exposure (HIE) in U.S. Military Service Academy (MSA) cadets and collegiate student-athletes." The consortium includes 50,000 military cadets/midshipmen and NCAA student-athletes from 30 participating collegiate institutions, representing 26 NCAA sports, military training, and other recreational activities. In addition, the CARE consortium has captured data on over 5,000

concussions – the largest concussion database. The CARE consortium is responsible for over 100 published papers influencing the improvement of sports participation for athletes of all ages.

The Consortium’s research was divided into three stages. The first focused on short-term outcomes of 6 months post-injury or less. The second phase focused on outcomes spanning the athletes’ collegiate career and five years after. The third and final phase was dedicated to understanding outcomes ten or more years after the initial injury. Many sources included in this review utilized data derived from the CARE consortium. Collectively, information compiled by the members of the CARE consortium provides unmatched power for insight into the various stages of concussion prevention, recovery, and long-term outcomes. This information will continue to shape concussion management in athletes of all ages for decades to come.¹¹

RISK OF FUTURE CONCUSSION IN PREVIOUSLY CONCUSSED ATHLETES

Growing evidence indicates that a history of concussion increases the likelihood of sustaining a future concussion in all populations, including athletes. One study evaluated over 12,000 athletes ranging from middle school to college age. Data showed that having a history of an SRC was the most significant risk factor for future concussion, outweighing contact sport participation.¹² An additional study with over 15,000 participants with a history of SRC reported nearly 600 subsequent concussions over the study period. The authors evaluated risk factors in collegiate athletes and army cadets of similar age. Results focused on both protective and risk factors associated with a subsequent concussion. Among the risk factors was a previous concussion.³ Schmidt et al.

investigated the additional modifier of age at first concussion among nearly 24,000 collegiate athletes and military cadets. Data showed that concussion during childhood is a significant risk factor for subsequent concussion, especially when compared to the group of individuals who’s first reported concussion occurred in adolescence. Moreover, data showed that with every one-year increase in the age of index concussion, there is a 16% reduction in the risk of subsequent concussion observed.¹³ Tanabe et al. examined 506 concussions, which occurred across 474 college students. This study reported that 47% of participants had a previous concussion within the previous year and that a history of concussion increased the risk of subsequent concussion by 4.5-fold in this population.¹⁴ The CARE consortium examined over 10,000 military cadets from three different academies and found that a history of previous concussion and female sex were the most consistent estimators of

Table 1. Studies Investigating Risk of Future Concussions

Study Referenced	Findings Summarized
Castellanos et al. 2021	History of concussion is listed as a risk factor for future concussion
Brett et al. 2018	History of concussion was the most significant risk factor for future concussion in athletes age middle school to college
Schmidt et al. 2018	Earlier age of first concussion increased risk of subsequent concussion
Tanabe et al. 2021	History of concussion increased the risk of subsequent concussion by 4.5-fold in the collegiate athletes included in this study
Van Pelt et al. 2019	Among 12,000 military cadets, history of previous concussion and female sex were the most consistent estimators of concussion risk across all settings. Females are 2.02 times more likely to experience a concussion.
Abrahams et al. 2014	A review on risk factors associated with SRC cited 10 studies that list previous concussion as a risk factor and 3 that found no difference
Gibbs et al. 2017	No increased incidence was associated with history of concussion among a group of Australian football players
Curry et al. 2019	16.2% recurrence rate of concussion, with increased risk associated with increased age at index concussion in a pediatric population

concussion risk across all settings. Interestingly, authors report that compared to males, females had 2.02 times the risk of concussion regardless of injury setting.¹⁵

A separate review article evaluated 86 studies and identified 14 risk factors associated with SRC. Of these studies, 13 questioned whether or not a previous concussion was a risk factor for future SRC, and 10 concluded that it was. The remaining three studies showed no difference.¹⁶ Additionally, one study examined professional Australian football players over 14 years. This study assessed 116 concussed athletes and 140 total concuss-

ions and reported no increased incidence associated with previous concussions.¹⁷ In a somewhat different approach, Curry et al. sought to quantify, rather than qualify, the risk imposed by a history of concussion. In a pediatric population of 536 patients, authors assessed the risk of experiencing a repeat concussion after the index concussion over the following two years. The study found a 16.2% recurrence rate, with increased risk associated with increased age at index concussion.¹⁸

While some studies failed to find a significant trend, there seems to be overwhelming evidence in favor of previous concussions predisposing individuals to future concussions. It is also worth noting that evidence points to a correlation of younger age at first concussion with greater numbers of concussions over time, younger athletes have less developed frontal lobe structure and factors such as these are likely clinically significant. It is well established that undeveloped frontal lobes are associated with increased risky behavior. This sense of invincibility and fearlessness may be exacerbated by additional frontal lobe damage, such as injury sustained by a concussion.^{19,20} Brain

development in humans is thought to be incomplete until roughly their mid-twenties. This risky behavior may include fabricated resolution of symptoms to RTP sooner. For many athletes, considerations of the risks associated with repeated concussions may be lacking therefore increased education and information to athletes, coaching staff, etc., is needed. Additionally, it is well known that some field positions predispose athletes to concussions more so than others.²¹ Future studies to investigate how history of concussion and concussion pathophysiology synergize to create increased risk for future concussions are necessary for improved outcomes.

IMPACT OF REPEATED CONCUSSION ON RETURN TO PLAY

One of the primary motivations for studying SRC is understanding when it is safe for athletes to return to play (RTP). RTP is defined as the time at which an athlete returns to their sport in full capacity. Athletes may resume play in a limited capacity sometime during the post-concussive period, but they are not considered to have fully returned until they are without limitations. The timeline for RTP is different for every athlete and for every injury, with some athletes not being medically cleared to return at all. As our understanding increases, many factors may contribute to changing these guidelines. In this section, we present several studies addressing if multiple concussions or cumulative damage contribute to longer RTP times? Additionally, we are interested in determining how contributing factors such as sex, age, and sport played affect this data.

Multiple studies report data suggesting that with greater numbers of concussions sustained comes longer RTP time. One study found that median RTP time was lengthened in athletes who had sustained three or more

concussions when compared to athletes with two or fewer. Additionally, the authors note that sex and sport had minimal effect on RTP time, suggesting a unified approach to RTP protocol across cohorts.¹⁰ Two studies found a cumulative effect on the number of concussions and the risk for prolonged RTP time. Cuff et al. found a significantly increased adjusted risk ratio for prolonged recovery with subsequent concussions. For nearly 5,000 patients aged 10-18, the risk increased from one concussion to two and from two to three or more.²² Similarly, Wang et al. found a cumulative effect for the risk of prolonged RTP time with increased numbers of concussions. The study included 159 NCAA student-athletes. Interestingly, modifiers such as sex and age had no effect. However, data showed that athletes in individual rather than team sports were at greater risk for prolonged RTP.²³

Not all studies discussed in this section directly address RTP time in collegiate athletes. However, prolonged concussion symptoms may lead to prolonged RTP. For instance, one study assessed the impact of repeated concussions in 430 patients aged 13-33. This study found a significant increase in sleep disturbances and concussion duration with increasing numbers of concussions.²⁴ Furthermore, in a pediatric prospective cohort study, including over 3000 children ranging from ages 5-18, researchers found that most children were symptom-free at one-year post-concussion. However, children who had sustained repeated concussions were significantly more likely to struggle with concussion symptoms beyond one year.²⁵ Similarly, in a study with 280 patients aged 11-22, Eisenberg et al. demonstrated a cumulative effect of the number of concussions on symptom duration.²⁶ Zuckerman et al. assessed the odds ratio of suffering from post-concussion syndrome (PCS) in 1507

Table 2. Studies Investigating Concussion Impact on Return to Play

Study Referenced	Findings Summarized
Zuckerman et al. 2016	Recurrent concussions resulted in a significantly increased odds ratio of PCS in NCAA athletes.
Broglio et al. 2023 Gibbs et al. 2017 Seifert et al. 2017	Comorbid conditions such as ADD, ADHD, anxiety, depression, OCD, and chronic headache increased duration of symptomatic course.
Broglio et al. 2022	RTP time was lengthened in athletes who had sustained three or more concussions when compared to athletes with two or fewer. Sex and sport had minimal effect.
Cuff et al. 2022	An increased risk of prolonged recovery was observed with an increasing number of concussions.
Wang et al. 2022	There was a cumulative effect of number of concussions on RTP time. Also, athletes in individual not team sports had greater risk of increased RTP time.
Oyegbile et al. 2020	Increased sleep disturbances and concussion duration was observed with increased concussions.
Van Ierssel et al. 2021	Children who sustained repeated concussions were significantly more likely to struggle with concussion symptoms than those sustaining only one concussion.
Eisenberg et al. 2013	A cumulative effect of the number of concussions on symptom duration was reported.
Taubman et al. 2016	Children with a history of multiple concussions paradoxically had the fastest recovery times.

NCAA student-athletes. Authors found that recurrent concussions resulted in a significantly increased odds ratio of PCS.⁵

Conversely, we found two studies that either showed no effect of repeated concussions on recovery/RTP time or showed an inverse relationship. In a study with 431 athletes aged 10-21 with an SRC, clinicians found no significant difference in recovery time in those with a history of concussion compared to those without. However, their analyses did not consider the number of previous concussions, and the authors found that males recovered faster than females, regardless of concussion history. Interestingly, Taubman et al. reported in a pediatric population of 90 patients that recovery time was significantly faster in both the history of concussion group and the history of multiple concussions group when compared to the group of children with no history of concussion. Further, the group with a history of

multiple concussions showed the fastest recovery time of all groups.²⁷

Multiple factors likely contribute to recovery time in athletes. These include but are not limited to age, sex, numbers of previous concussions, region of the brain impacted, and force of the impact. Additionally, comorbid conditions such as ADD, ADHD, anxiety, depression, and OCD are known to have an increased duration of symptomatic course and subsequently increased time needed to return to play.^{8,17} Similarly, athletes with other comorbid conditions such as headache and migraine also may be at greater risk for extended duration of return to play. This relationship between chronic headache and acute

concussion is complex. A post-traumatic headache can be improperly diagnosed as a primary headache disorder such as migraine or tension headache. Conversely, some athletes are misdiagnosed with concussion when they are simply having a primary headache exacerbation.²⁸ The complexity of concussion and the diversity of recovery add to the difficulty of diagnoses and prognoses.

IMPACT OF INTERVAL BETWEEN CONCUSSIONS ON RECOVERY TRAJECTORY

Current concussion management dictates that athletes do not return to play until they are symptom-free, as there is a window of vulnerability for repeat concussions in the days following the injury. This becomes particularly pertinent when considering the phenomenon of second impact syndrome (SIS). SIS is a condition in which an individual experiences a second head injury before complete recovery from an initial head injury. The pathophysiology of SIS is poorly understood, but the proposed mechanism is linked to disrupted autoregulation of intracerebral blood flow, causing increased intracranial

pressure, followed by eventual brainstem herniation.²⁹ However, symptom reporting is subjective in nature, particularly in young athletes, who are motivated to RTP as quickly as possible. Hence, the task of determining when an athlete is truly symptom free becomes paramount in determining a safe RTP interval.

In athletes, most subsequent concussions occur within 7-10 days of the prior injury.³⁰ One study found that 92% of repeat concussions occurred within ten days.³¹ While it is widely accepted that patients are particularly vulnerable in the interval following an initial concussion, it is less well-established how the length of the interval between concussions impacts the trajectory of recovery. In this section, we present trends in the literature regarding intervals between concussions and discuss how modifiers such as sex and age may impact outcomes. In a review examining vulnerabilities following mild traumatic brain injury (mTBI), Greco et al. pointed out that there is a period during which there is an increased risk for subsequent injuries with slower recovery of neurological function. The authors also highlight a significant lack of literature examining sex differences as it pertains to risk for repeat concussions.³²

In the previously mentioned study by Eisenberg et al., children with a previous

Table 3. Studies Investigating Impact of Time Between Concussions

Study Referenced	Findings Summarized
Eisenbert et al. 2023	Children with a previous concussion within the past year had significantly longer recovery times when compared to those with first-time concussions or with previous concussions more than a year prior.
McCrea et al. 2020	92% of repeat concussions occurred within ten days of initial concussion.
Remigio-Baker et al. 2021	Participants with more recent concussion history experienced significantly worse symptomatology.
Cools et al. 2022	NFL players took longer to RTP from concussion if they suffered a previous concussion within the prior 12 months when compared with those who had not.
Brett et al. 2019	Patients with a higher mean diffusivity on imaging seven days post-RTP were significantly more likely to sustain a repeat concussion.

concussion within the past year had significantly longer recovery times when compared to those with a first-time concussion or with previous concussions more than a year prior. Moreover, loss of consciousness upon any of the head impacts significantly lengthened recovery.²⁶ Moreover, eighty-four military service members ranging from 18-44 years of age who sustained a concussion within 72 hours of enrollment in the study were divided into three groups. The first group included participants with a recent history of concussion within six years but no sooner than one year. The second group included service members with a "remote" history of concussion of greater than six years. Lastly, the control group was participants who had just suffered their index concussion. While authors did not assess the duration of symptoms, participants with more recent concussion history experienced significantly worse symptomatology regarding the numbers and severity of symptoms. There was no difference between the remote and control groups.³³ Cools et al. assessed the RTP time for all 1,214 concussions in National Football League athletes from 2015-2019. This study found that players with repeat concussion took a median of 12 days to RTP. Athletes that either sustained their first concussion or only a single concussion within that year required a median of 9.5 and 9 days, respectively.³⁴

One compelling study used diffusion tensor imaging (DTI) to assess trends in mean diffusivity in white matter regions of interest in the brain that might predict repeat concussions. In a low-powered study with 82 concussed athletes, data showed that patients with a higher mean diffusivity on imaging seven days post-RTP were significantly more likely to sustain a repeat concussion within 12 months.³⁵ While this study had low numbers of participants, further

investigations suggest that factors, in addition to symptom duration, may dictate a

safe RTP and the likelihood of a repeat concussion.

Evidence suggests that the interval between concussions may impact the clinical course following a subsequent impact. From these data, it may be inferred that shorter intervals between concussions lead to worse clinical outcomes. However, most of these studies divide groups by crude intervals, such as months or years. Future studies using more finite intervals to separate groups would be helpful. Additionally, imaging characteristics may provide valuable insight into when athletes may RTP safely.

SUMMARY

With an enormous body of research and more sophisticated approaches to studying the complexities of SRC, we continue to learn more and more about prevention, recovery, and long-term outcomes. Despite the advances in understanding SRC, there are still gaps in our knowledge surrounding SRC and its long-term effects on collegiate athletes. In this review, we addressed some of the remaining questions surrounding SRC. Namely, does a history of concussions predispose one to future concussions? Do increasing numbers of concussions impact the RTP/recovery time? And lastly, does the interval between concussions impact recovery?

It is important to note that rates of reporting concussions are widely variable and subject to several factors. As we become more aware of the impacts of SRC on athletes acutely and as the patient ages, there may be a trend toward being overly cautious and overreporting. Yet, athletes are motivated to remain active in their sport and may be likely to hide or underreport symptoms

when possible. Thus, education, observation, and prompt medical intervention, when necessary, are of the utmost importance.

The evidence thus far seems to suggest that a history of concussion may increase the risk of sustaining a concussion upon head impact. Five studies support this notion.^{3,12-15} Additionally, we found a separate review article that cited ten sources that listed previous concussions as a risk factor for future concussions and only three sources that found no significant difference.¹⁶ While it is helpful to acknowledge that sustaining previous concussions are a risk factor for future concussions, it would be beneficial to understand the mechanism(s) that contribute to this idea. Perhaps future research can define what measures could be taken in the acute phase of an index concussion to prevent future susceptibility.

We also found convincing evidence in our sources to suggest that increasing concussions prolongs RTP/recovery time. This review includes six studies that support this claim.^{5,10,22-25} We included one study that reported no significant difference in RTP between individuals with or without previous

concussion history. However, the study did not consider the number of prior concussions.²⁶ Also, one study showed an inverse relationship between the number of concussions and recovery time in a pediatric population. However, this study had a considerably small sample size.²⁷ In future research, it would be interesting to quantify the impact of an increasingly higher number of concussions on RTP. None of the studies included in this review analyzed the effects beyond three concussions.

Lastly, all six papers investigating the interval between concussions point to its significant impact on the clinical course following a repeat concussion.^{26,31-35} In this section, we also included an interesting study that used brain imaging technology to correlate specific imaging characteristics with the risk of repeat concussions. In summary, more targeted research to consider and identify factors such as numbers of previous concussions, age at index and subsequent concussions, the time between concussions, and individual recovery trends post-concussion(s), is warranted.

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