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## Immediate Removal From Activity After Sport-Related Concussion Is Associated With Shorter Clinical Recovery and Less Severe Symptoms in Collegiate Student-Athletes

Breton M. Asken, MS, ATC\*, Russell M. Bauer, PhD, Kevin M. Guskiewicz, PhD, ATC, Michael A. McCrea, PhD, Julianne D. Schmidt, PhD, ATC, Christopher C. Giza, MD, Aliyah R. Snyder, MS, Zachary M. Houck, MS, Anthony P. Kontos, PhD, Thomas W. McAllister, MD, Steven P. Broglio, PhD, ATC, James R. Clugston, MD, MS, CARE Consortium Investigators  
Investigation performed at the University of Florida, Gainesville, Florida, USA

### Abstract

**Background:** Timely removal from activity after concussion symptoms remains problematic despite heightened awareness. Previous studies indicated potential adverse effects of continuing to participate in physical activity immediately after sustaining a concussion.

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\*Address correspondence to Breton M. Asken, MS, ATC, Department of Clinical and Health Psychology, University of Florida, PO Box 100165, Gainesville, FL 32610, USA (basken8@phhp.ufl.edu).

Breton M. Asken, MS, ATC (Department of Clinical and Health Psychology, University of Florida, Gainesville, Florida, USA); Russell M. Bauer, PhD (Department of Clinical and Health Psychology, University of Florida, Gainesville, Florida, USA); Kevin M. Guskiewicz, PhD, ATC (College of Arts and Sciences, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina, USA); Michael A. McCrea, PhD (Department of Neurology, Medical College of Wisconsin, Milwaukee, Wisconsin, USA); Julianne D. Schmidt, PhD, ATC (Department of Kinesiology, University of Georgia, Athens, Georgia, USA); Christopher C. Giza, MD (Department of Pediatrics, University of California, Los Angeles, Los Angeles, California, USA); Aliyah R. Snyder, MS (Department of Clinical and Health Psychology, University of Florida, Gainesville, Florida, USA); Zachary M. Houck, MS (Department of Clinical and Health Psychology, University of Florida, Gainesville, Florida, USA); Anthony P. Kontos, PhD (Department of Orthopaedic Surgery, University of Pittsburgh, Pittsburgh, Pennsylvania, USA); Thomas W. McAllister, MD (Department of Psychiatry, School of Medicine, Indiana University, Indianapolis, Indiana, USA); Steven P. Broglio, PhD, ATC (Department of Kinesiology, NeuroTrauma Research Laboratory, University of Michigan, Ann Arbor, Michigan, USA); James R. Clugston, MD, MS (Department of Community Health and Family Medicine, University of Florida, Gainesville, Florida, USA); CARE Consortium Investigators: Scott Anderson, ATC (University of Oklahoma, Norman, Oklahoma, USA); Jeff Bazarian, MD, MPH (Department of Emergency Medicine, School of Medicine and Dentistry, University of Rochester, Rochester, New York, USA); Alison Brooks, MD, MPH (School of Medicine and Public Health, University of Wisconsin–Madison, Madison, Wisconsin, USA); Thomas Buckley, EdD, MS, ATC (Department of Kinesiology and Applied Physiology, University of Delaware, Newark, Delaware, USA); Sara Chrisman, MD, MPH (Department of Pediatrics, Seattle Children's Research Institute, Seattle, Washington, USA); Michael Collins, PhD (Department of Orthopaedic Surgery, University of Pittsburgh, Pittsburgh, Pennsylvania, USA); John DiFiori, MD (Division of Sports Medicine and Non-operative Orthopaedics, University of California, Los Angeles, Los Angeles, California, USA); Stefan Duma, PhD (School of Biomedical Engineering and Sciences, Virginia Tech–Wake Forest University, Blacksburg, Virginia, USA); Brian Dykhuizen, MS, ATC (Wilmington College, Wilmington, Ohio, USA); James T. Eckner, MD, MS (Department of Physical Medicine and Rehabilitation, University of Michigan, Ann Arbor, Michigan, USA); Luis Feigenbaum, DPT (Department of Physical Therapy, University of Miami, Coral Gables, Florida, USA); April Hoy, MS, ATC (Director of Sports Medicine and Wellness, Azusa Pacific University, Azusa, California, USA); Louise Kelly, PhD (Department of Exercise Science, California Lutheran University, Thousand Oaks, California, USA); T. Dianne Langford, PhD (Lewis Katz School of Medicine, Temple University, Philadelphia, Pennsylvania, USA); Laura Lintner, DO (Department of Family and Community Medicine, Wake Forest School of Medicine, Winston-Salem, North Carolina, USA); Gerald McGinty, PT, DPT, OCS, SCS (US Air Force Academy, Colorado Springs, Colorado, USA); Jason Mihalik, PhD, ATC (Department of Exercise and Sport Science, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina, USA); Christopher Miles, MD (Department of Family and Community Medicine, Wake Forest School of Medicine, Winston-Salem, North Carolina, USA); Justus Ortega, PhD (Department of Kinesiology and Recreation Administration, Humboldt State University, Arcata, California, USA); Nicholas Port, PhD (School of Optometry, Indiana University, Bloomington, Indiana, USA); Margot Putukian, MD (Director of Athletic Medicine, Princeton University, Princeton, New Jersey, USA); Steve Rowson, PhD (Virginia Tech–Wake Forest University Center for Injury Biomechanics, Blacksburg, Virginia, USA); Steven Svoboda, MD (US Military Academy, West Point, New York, USA).

**Hypothesis/Purpose:** The purpose was to determine the effect of timing of removal from play after concussion on clinical outcomes. It was hypothesized that immediate removal from activity after sport-related concussion (SRC) would be associated with less time missed from sport, a shorter symptomatic period, and better outcomes on acute clinical measures.

**Study Design:** Cohort study; Level of evidence, 3.

**Methods:** Data were reported from the National Collegiate Athletic Association and Department of Defense Grand Alliance: Concussion Awareness, Research, and Education (CARE) Consortium. Participants with 506 diagnosed SRCs from 18 sports and 25 institutions and military service academies were analyzed and classified as either immediate removal from activity (I-RFA) or delayed removal from activity (D-RFA). Outcomes of interest included time missed from sport attributed to their SRC, symptom duration, and clinical assessment scores.

**Results:** There were 322 participants (63.6%) characterized as D-RFA. I-RFA status was associated with significantly less time missed from sport ( $R^2$  change = .022–.024,  $P < .001$  to  $P = .001$ ) and shorter symptom duration ( $R^2$  change = .044–.046,  $P < .001$  [all imputations]) while controlling for other SRC recovery modifiers. These athletes missed approximately 3 fewer days from sport participation. I-RFA athletes had significantly less severe acute SRC symptoms and were at lower risk of recovery taking 14 days (relative risk = .614,  $P < .001$ , small-medium effect size) and 21 days (relative risk = .534,  $P = .010$ , small effect size).

**Conclusion:** I-RFA is a protective factor associated with less severe acute symptoms and shorter recovery after SRC. Conveying this message to athletes, coaches, and others involved in the care of athletes may promote timely injury reporting.

## Keywords

brain injury; concussion reporting; CARE Consortium; mTBI

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Recognition and reporting of sport-related concussion (SRC) have improved in the past 2 decades, owing to media attention, improvements in injury detection and diagnosis, changing attitudes toward injury reporting in sports culture, and the implementation of systematic protocols for concussion management.<sup>18,21,26</sup> Athlete-specific studies showed that symptoms commonly subside within approximately 7 to 14 days after injury.<sup>30–32</sup>

Current SRC management guidelines recommend that athletes who are suspected of sustaining a concussion be immediately removed from play and medically evaluated.<sup>35</sup> However, as many as 50% of athletes either fail to disclose their injuries or are delayed in being removed from athletic participation.<sup>1,33</sup> This is most often due to the difficulty in determining the seriousness of their symptoms, poor awareness and education about concussion, a desire to remain in play, and concerns about coaches' reactions.<sup>4,7,33,45</sup> A recent preliminary study of collegiate athletes demonstrated that athletes who were not immediately removed from practice or game play after an SRC took approximately 5 days longer to return to play (RTP), a finding that may motivate athletes, coaches, and sports institutions to take timely SRC reporting seriously.<sup>1</sup> This study used retrospective medical chart review at a single collegiate institution and did not account for acute injury factors,

such as loss or alteration of consciousness. It also did not include any clinical measures, such as acute symptom, cognitive, or balance examinations.

Three similar studies examined adolescent athletes. Two reported that athletes who continued to play took twice as long to recover and had more substantial cognitive impairment and symptoms than those who were immediately removed.<sup>12,20</sup> Another study investigated the effect of sustaining an additional head impact sufficient to worsen already existing symptoms and found that an additional impact, not simply continuation of play, lengthened recovery and resulted in more severe symptoms.<sup>46</sup> These studies involved young cohorts, emanated from specialized concussion referral clinics, were retrospective, or lacked sufficient sample sizes to conduct more in-depth analyses of covariates. The purpose of the present study was to prospectively examine removal from athletic activity and its effect on sport time lost because of SRC and performance on acute clinical measures in a large sample of collegiate athletes. In so doing, we hoped to provide empirical evidence of recovery benefit in immediate removal of athletes from play after SRC.

## METHODS

### Study Design and Setting

Data were obtained from the National Collegiate Athletic Association and Department of Defense Concussion Assessment, Research, and Education (CARE) Consortium. The CARE Consortium has prospectively collected SRC-related assessment data on student-athletes since 2014 and currently consists of 30 universities, including 4 US military service academies across the country. Student-athletes at participating institutions complete annual preseason baseline test batteries, which are repeated in the event of a suspected concussion. The battery includes, at a minimum, an assessment of concussion-like symptoms, cognition, and postural stability. They also complete a clinical reporting form describing sport participation history, academic history, personal and family medical history, and socioeconomic status. Clinicians complete a postinjury clinical reporting form describing concussion-related factors, such as timing, mechanism of injury, player reporting characteristics (eg, immediate or delayed reporting, presence of delayed symptom onset), and acute indicators of injury severity (eg, observed mental status and level of consciousness) (see the Appendix, available in the online version of this article). A detailed description of the CARE Consortium methods is provided elsewhere.<sup>5</sup> Institutional review board approval was obtained by the lead study site, and the Human Research Protection Office of the US Department of Defense further reviewed and approved the CARE Consortium study protocol. Individual sites also obtained local institutional review board and subsequent Human Research Protection Office approval.

### Participants

The initial data set contained information from 815 SRCs occurring between August 2014 and September 2016. Our final analyses included 506 SRCs sustained across 18 sports at 22 institutions: 62.1% of initial data set, 311 men (61.5%), 193 women (38.2%), 2 unknown (0.3%). Figure 1 describes exclusion criteria and the process of case removal. Athletes with

>1 concussion (“repeat concussions”) had only their initial concussion included so that each participant contributed equally to the data set.

## Measures

Our primary independent variable was removal from activity (RFA) status, coded as immediate RFA (I-RFA) or delayed RFA (D-RFA). We ascertained RFA status via 2 yes/no questions completed by clinicians on the postinjury clinical reporting form: “Did the athlete immediately report the injury?” and “Was the athlete immediately removed from play?” Table 1 describes the RFA classification algorithm and associated sample size based on the clinician responses to these 2 questions. A “yes” response to both questions classified participants as I-RFA (ie, removal from play coincident with concussion-causing impact). A response of “no” to either of the 2 questions warranted classification as D-RFA (ie, removal from play noncoincident with concussion-causing impact). For example, if a clinician responded to “Did the athlete immediately report the injury?” with “no” but responded to “Was the athlete immediately removed from play?” with “yes,” this was interpreted as a scenario where the athlete delayed reporting the injury and thus continued participating in athletic activity but was then removed from activity immediately after eventual evaluation/diagnosis. Cases of missing data for question 1 or 2 with a corresponding “yes” response to the other question were excluded from analyses, since it was unclear if the athlete continued participating, as were cases of missing data for both questions ( $n = 117$ ).

The primary outcome variable was total time lost attributed to SRC (measured in days), beginning on the clinician-reported date and time of concussion and ending on the date on which the athlete received clearance for unrestricted RTP. This represents the combined duration of the time from injury until graduated RTP was begun plus the time required for completion of a graduated RTP protocol through unrestricted RTP for noncollision sport athletes and clearance for full contact participation for collision sport athletes, which corresponds to stage 5 of most standard RTP protocols.<sup>34,35</sup> Cases of missing data ( $n = 120$ ) were excluded, and so were statistical outliers ( $n = 6$ , time lost to concussion  $>3$  SD above sample mean). Differences in clinician-indicated duration of symptoms were analyzed in a subset of 429 student-athletes with these data available. This approximately reflects the elapsed time between point of injury and initiation of the RTP protocol, although clinicians may commonly begin early stages of the protocol if an athlete reports only minor symptoms.

We considered covariates that, per previous literature, may lengthen recovery time. These included noninjury-related factors<sup>10,19,22,36,39,43,49</sup> and injury-related factors<sup>22,25,27,28,35,36</sup> obtained from baseline and postinjury clinical reporting forms. Table 2 describes the sample characteristics. Age was not included as a covariate, given the homogeneity of the sample (mean  $\pm$  SD,  $19.6 \pm 1.3$  years) and the lack of difference between RFA groups ( $t_{500} = .997$ ,  $P = .313$ ).

Data were unavailable for evaluating whether any athletes sustained additional head impacts while continuing to participate after SRC versus just continued exertion. We attempted to address the differentiation by comparing groups of D-RFA athletes based on assumed risk of exposure with additional head impacts within their sport. Football athletes ( $n = 111$ ) were compared with a group of athletes from sports with lower risk of head impacts ( $n = 65$ ):

basketball (n = 41), swimming (n = 11), cross-country/track (n = 3), baseball (n = 5), rowing/crew (n = 4), and tennis (n = 1).

Secondary outcome variables included clinical concussion measures obtained at 2 acute time points after injury, 0 to 6 hours (time 1) and 24 to 48 hours (time 2), in a subset of the initial sample with complete data (see Table 2 for associated sample sizes). Measures included the Sport Concussion Assessment Tool–Third Edition (SCAT3)<sup>36</sup> total number of symptoms and symptom severity score, Brief Symptom Inventory 18 (BSI-18; time 2)<sup>9</sup> total score, the Standardized Assessment of Concussion<sup>34</sup> (SAC) total score, and Balance Error Scoring System<sup>40</sup> (BESS) total score. Acute symptom severity has been associated with recovery duration.<sup>22</sup> This factor was not included in the regression model, because <50% of the participants had these data available. Participants with missing symptom data were disproportionately classified as D-RFA ( $\chi^2 = 20.597$ ,  $df = 506$ ,  $P < .001$ ) and significantly differed on time missed from sport ( $t_{504} = 22.239$ ,  $P = .026$ ) and duration of symptom expression ( $t_{427} = 2.993$ ,  $P = .003$ ). Therefore, we compared RFA groups on acute symptom severity separately with the understanding that these RFA groups may not be representative of the larger sample.

A phenomenon of interest is that of delayed symptom onset after SRC, a factor potentially related to delayed symptom reporting or removal. Thus, in a final analysis, we evaluated our primary outcome variables of time missed from sport and symptom duration in D-RFA and I-RFA student-athletes with and without reported delayed symptom onset.

## Statistical Methods

Analyses were performed with SPSS (v 22; IBM). All outcome variables were evaluated for normality. Several outcome variables were significantly skewed and thus transformed before analyses such that the  $z(\text{skew})$  statistic was  $P > .05$ .

A 3-step hierarchical regression was used to evaluate the unique contribution of RFA status to variance in time lost because of SRC and symptom duration, controlling for noninjury- and injury-related factors (Table 2). All covariates remained in the model regardless of significance at each step.<sup>22,35</sup> The same method was used for the analysis based on collision sport participation within the D-RFA group. We examined associations among covariates (noninjury and injury related) and RFA status with chi-square tests and independent samples  $t$  tests.

For our secondary aims, we used multivariate analyses of variance to evaluate the effect of RFA group on acute symptom scores (SCAT3 symptom total and severity) at time 1 and time 2 (SCAT3 symptom total and severity and BSI-18). Analyses of variance evaluated main effects and interactions associated with time missed from sport and symptom duration with 2 fixed factors: RFA status and presence/absence of delayed symptom onset. SAC and BESS performances at time 1 and time 2 were compared with independent samples  $t$  tests. A priori significance was set at  $P < .05$  for all analyses and Bonferroni-adjusted for multiple comparisons.

## RESULTS

After outlier removal, 506 patients were eligible for analyses. The included cases did not differ statistically from excluded cases on predictor or outcome variables. We imputed missing data related to noninjury- and injury-related factors (see Table 2) to preserve the original sample size.<sup>14</sup> Twenty imputations were performed. The ranges of values obtained across the 20 imputations are reported when pooled statistics are not provided.

Table 3 provides descriptive statistics for all outcome variables stratified by RFA group. Groups did not differ statistically on any noninjury predictors ( $P > .05$  for all analyses). Athletes with loss of consciousness (LOC) ( $\chi^2 = 8.57$ ,  $df = 501$ ,  $\phi = -0.131$ , small effect size) or alteration of consciousness ( $\chi^2 = 22.77$ ,  $df = 496$ ,  $\phi = -0.214$ , small-medium effect size) at the time of injury were significantly more likely to be in the I-RFA group.

### Effect of RFA Status on Recovery Times

Neither noninjury- nor injury-related factors significantly predicted time lost because of SRC (model 1:  $R^2 = 0.012$ – $0.021$ ,  $F_{7,498} = 0.900$ – $1.522$ ,  $P = .157$ – $.506$ ; model 2:  $R^2$  change =  $0.004$  [all imputations],  $P = .518$ – $.613$ ,  $F_{10,495} = 0.821$ – $1.274$ ,  $P = .242$ – $.609$ ). None of the individual model 1 or model 2 predictors significantly predicted time lost attributed to SRC ( $P > .05$  for all factors). Results were similar when symptom duration was used as the outcome variable.

RFA status significantly improved upon model 2 (model 3:  $R^2$  change =  $0.022$ – $0.024$ ,  $P < .001$  to  $P = .001$ ), and model 3 significantly predicted time lost because of SRC ( $F_{11,494} = 1.865$ – $1.294$ ,  $P = .010$ – $.042$ ). Controlling for all other factors in the model, RFA status was the only factor to significantly predict time lost attributed to SRC ( $B = 2.95$  [pooled],  $\beta = 0.154$ – $0.161$ ,  $P < .001$  to  $P = .001$ , small effect size). Immediate removal from athletic activity resulted in approximately 3 fewer days lost because of SRC than that seen in D-RFA participants. Similarly, RFA status significantly improved upon model 2 in predicting duration of symptom expression ( $R^2$  change =  $0.044$ – $0.046$ ,  $P < .001$  [all imputations]). Controlling for all other factors in the model, RFA status was the only factor to significantly predict symptom duration ( $B = 2.02$  [pooled],  $\beta = 0.217$ – $0.223$ ,  $P < .001$  [all imputations], small effect size).

Group differences in recovery trajectories are shown in Figure 2. We evaluated the relative risk (RR) of I-RFA participants missing 14 days and 21 days from sport participation. I-RFA athletes had a 39% lower likelihood of taking 14 days ( $\chi^2 = 12.663$ ,  $df = 2$ ,  $506$ ,  $P < .001$ ,  $\phi = 0.158$ ,  $RR = .614$ , small-medium effect size) and 47% lower likelihood of taking 21 days ( $\chi^2 = 6.620$ ,  $df = 2$ ,  $506$ ,  $P = .010$ ,  $\phi = 0.121$ ,  $RR = 0.534$ , small effect size) to achieve full RTP clearance than D-RFA athletes.

Football participation was not associated with longer time lost because of SRC when compared with participation in sports with low risk of repeat head impacts ( $P > .05$  for all regression statistics). Results were similar when the higher-risk sport group was broadened to include soccer and hockey student-athletes.



### Effect of RFA Status on Acute Symptoms and Clinical Measures

At time 1, there was a significant omnibus effect of RFA group on SCAT3 symptom evaluation outcome scores (Pillai trace  $F_{2,315} = 5.080$ ,  $P = .007$ , partial  $\eta^2 = 0.031$ ). I-RFA student-athletes reported significantly fewer SCAT3 symptoms ( $P = .003$ , Cohen  $d = 0.330$ , small-medium effect size) and significantly lower SCAT3 symptom severity ( $P = .024$ , Cohen  $d = 0.259$ , small-medium effect size). Groups did not differ on SAC or BESS scores at time 1. BSI-18 was not performed at time 1.

At time 2, there was also a significant omnibus effect of RFA group on acute symptom scores (Pillai trace  $F_{3,228} = 4.319$ ,  $P = .006$ , partial  $\eta^2 = .054$ ). I-RFA student-athletes reported significantly fewer SCAT3 symptoms ( $P = .009$ , Cohen  $d = 0.360$ , small-medium effect size), significantly lower SCAT3 symptom severity ( $P = .027$ , Cohen  $d = 0.293$ , small-medium effect size), and significantly lower BSI-18 total score ( $P = .002$ , Cohen  $d = 0.403$ , small-medium effect size). Groups did not differ on SAC or BESS scores at time 2.

### Effect of Delayed Symptom Onset

A significantly higher proportion of D-RFA student-athletes reported delayed symptom onset ( $\chi^2 = 54.089$ ,  $df = 497$ ,  $P < .001$ ,  $\phi = 0.330$ , moderate effect size). Of 318 D-RFA student-athletes analyzed, 153 (48.1%) had delayed symptom onset, as opposed to just 27 of 179 (15.1%) I-RFA student-athletes with available data. For time missed from sport and duration of symptom expression, analyses of variance revealed a main effect of RFA group only ( $F_{1,493} = 6.916$ ,  $P = .009$ ;  $F_{1,417} = 6.984$ ,  $P = .009$ , respectively). There was no main effect of delayed symptom onset and no interaction effect of delayed symptom onset and RFA group on recovery outcomes ( $P > .05$  for all effects).

## DISCUSSION

Student-athletes immediately removed from athletic activity after an SRC had significantly less time lost—approximately 3 days—from sport when compared with athletes with D-RFA. They also experienced approximately 2 days' shorter duration of symptoms. The current study extended previous studies by controlling for several noninjury- and injury-related factors previously shown to moderate recovery from brain injury.<sup>†</sup> None of these other factors predicted time lost in our sample. Immediate removal from athletic activity was associated with a 39% lower likelihood of requiring 14 days and 47% lower likelihood of requiring 21 days to achieve full medical clearance for sport. Our secondary analyses also indicated that student-athletes with immediate removal had significantly fewer and less severe symptoms (SCAT3 and BSI-18) reported 0 to 6 and 24 to 48 hours after SRC. A recent systematic review concluded that acute symptom severity is the most consistent predictor of SRC clinical recovery.<sup>22</sup> This factor was not included in our overall regression model owing to missing data in over half of our sample, which disproportionately affected the D-RFA group as its time of reporting was frequently outside the acute period. However, these exploratory findings indicate a potential relationship between timing of removal from

<sup>†</sup>References 10, 11, 19, 25, 27, 28, 36, 39, 43.

athletic participation and acute symptoms, both of which have growing support as prognostic factors.

### Integration With Existing Literature

Our findings in this large multisite sample build on the results of recent investigations on the effects of continuing to play after SRC. In a retrospective chart review of 97 collegiate athletes, Asken and colleagues<sup>1</sup> reported that athletes who were immediately removed from play took approximately 5 fewer days to return to sport versus those with delayed removal from athletic activity (6.8 vs 12.3 days). In a prospective study of 64 adolescent athletes, Elbin and colleagues<sup>12</sup> reported that athletes who were immediately removed recovered 22 days sooner than those with delayed removal. The size of this difference may reflect the younger age of the sample, since younger age is a factor that is associated with a longer recovery time. Elbin et al<sup>12</sup> also reported that athletes with immediate removal performed better on a computerized neurocognitive measure and had less severe symptoms. We found similar effects on symptom severity despite different measurement time points (1–7 days and 8–30 days after injury vs 0–6 hours and 24–48 hours in the present study). While our results did not support findings of cognitive score disparities, the current study used only a brief cognitive screening measure. Terwilliger et al<sup>46</sup> reported an effect of additional head impacts sustained shortly after SRC. This was indirectly evaluated in the present study by comparing football student-athletes with D-RFA and student-athletes from sports with little to no risk of repetitive head impacts, but there was no effect. Importantly, Terwilliger et al<sup>46</sup> specifically identified individuals who reported sustaining a head impact that worsened already-existing SRC symptoms before removal from play, which may explain the discrepant findings. Additionally, participants from the Terwilliger et al<sup>46</sup> and Elbin et al<sup>12</sup> studies were recruited from a specialty clinic and may not represent concussed athletes who did not receive specialty referral.

Clinical and preclinical research offers plausible explanations for our results and supports a “window of vulnerability” after concussion.<sup>24</sup> Several animal studies reported adverse outcomes after physical exertion immediately after brain injury believed to result from heightened neuroinflammation and excitotoxicity.<sup>15,16</sup> Such findings could be attributable to other physiologic factors that compound the immediate effects of SRC, including elevated systemic blood pressure, heart rate, and/or body temperature.<sup>41,48</sup> Data suggest that prolonged rest may also increase risk of protracted recovery,<sup>8,13,44,47</sup> while properly timed physical activity could improve outcomes via mechanisms such as promoting upregulation of proteins important for neural repair and homeostatic restoration.<sup>17,38,42</sup> Consensus guidelines recommend a 24- to 48-hour period of relative rest immediately after SRC.<sup>35</sup> Future studies would do well to retrospectively quantify a dose-response effect for the amount of time that an athlete continues participating after a concussion and to measure adverse outcomes such as recovery time and functional impairment. This could also be validated prospectively through animal models. Other factors should also be considered, such as the intensity and nature of physical exertion and whether additional head impacts are incurred.<sup>45</sup>



## Educational and Clinical Considerations

Our data indicate that 63.6% (322 of 506) of athletes included in the sample had D-RFA after SRC. This percentage may overestimate the true incidence of this problem, since 117 cases were excluded because of missing data for RFA determination. Regardless, the rate in the current study is higher than that from Asken and colleagues,<sup>1</sup> who reported that approximately half (51.5%) of their retrospectively identified sample fit this description. There are many reasons why an athlete may not be immediately removed from participation after a concussion, so these high rates of delayed removal likely do not simply reflect athletes who willfully withheld symptoms or clinicians' non-compliance with concussion management regulations. For example, we found a high proportion of individuals with delayed symptom onset within the D-RFA group, possibly explaining why some student-athletes may continue participating after an SRC. If symptoms are not present immediately after a head impact, athletes may have difficulty associating later symptom development with a specific impact. However, the data showed that even athletes with delayed symptom onset who were removed from activity immediately upon recognition of symptoms and diagnosis had shorter symptom duration and time missed from sport than did athletes with delayed removal. Data suggest that removal at the point of symptom onset, even if delayed after the injurious impact, gives the best chance of avoiding prolonged recovery. The current findings underscore the importance of educating athletes, coaches, and medical personnel about symptom reporting and identification immediately after SRC. In so doing, we may help reduce the chance that an athlete is removed from athletic and academic participation for extended periods, potentially reducing or avoiding adverse outcomes such as depression, stress, or anxiety.<sup>29,37</sup>

In the current study, there was a disproportionate prevalence of LOC and alteration of consciousness in the I-RFA group. This is expected since these are overt signs of injury that are easily identified by medical personnel, resulting in immediate removal. Although prolonged LOC may reflect more serious brain injuries, the role of brief LOC in predicting severity of SRC is less clear.<sup>6,22,27,28,36</sup> In our study, LOC and alteration of consciousness were less prevalent in the D-RFA group, yet the D-RFA student-athletes missed more time than did their I-RFA counterparts. This further argues that delayed removal per se is a risk factor for prolonged recovery time.

## Limitations

A primary limitation of the present study pertains to missing data. The original data set contained 815 participants with a diagnosed concussion, but only 506 had the requisite predictor variable data (sufficient for determining RFA status) and outcome data (time missed from sport excluding outliers). The preceding analyses and results are predicated upon the assumption that the 506 participants were representative of the original 815, and we have no clear reason to suspect that data were not missing at random. However, missing data may systematically influence findings either in support of or in opposition to the null hypothesis, generally increasing uncertainty of results. Prior studies reporting similar results raise confidence in the present findings, but future research efforts should prioritize data completeness to ensure representativeness of the sample.

This study relied on clinician report and athlete self-report for many of the predictors used in our analyses. Particularly for athletes with longer participation in athletic activity after SRC, clinicians may have had to estimate the date and time of the injury. Athletes who continued participation may include those who attempted to play through symptoms but then reported their symptoms after they did not resolve. In contrast, athletes who initially hid their symptoms but may have spontaneously recovered and never reported them would not be included within the data set. Similarly, athletes who immediately stopped participating after SRC may hide the fact that they had actually begun experiencing symptoms before reporting their injury to medical staff. Clinician interpretation of how to define/record timing of symptom report and timing of removal may result in inconsistent group classification. For example, 27 student-athletes were classified as “immediate removal” but also indicated delayed symptom onset. Conceivably, the clinician thought a classification of “immediately reported” was warranted if the student-athlete reported the injury as soon as she or he experienced symptoms, even if the SRC-causing mechanism occurred earlier in the event. Another scenario is that of a clinician’s monitoring or evaluating an asymptomatic athlete after observation of a significant impact as a precautionary measure, and the athlete then develops symptoms while being monitored. In this case, it may not be considered “immediate report,” but the athlete had still ceased physical activity immediately after getting concussed. Other clinicians may define this differently, and future studies should refine this classification procedure to yield more homogeneous samples. Last, considering a diagnostic certainty rating as reported retrospectively by the clinician may be beneficial in future research since the nonspecificity of concussion symptoms<sup>2,3,23</sup> and/or delayed symptom onset could introduce clinical uncertainty regarding symptom attribution and contribute to further heterogeneity within the study sample.

## CONCLUSION

Immediate removal from athletic participation after SRC may optimize recovery (shorter symptom duration and less total time missed from sport) and result in less severe acute symptoms in collegiate athletes. Removal from sport should be considered among the many factors traditionally considered important predictors of recovery, including pre-existing psychiatric disorder, prior SRC, and LOC at time of injury.

Athletes should engage medical staffs and report symptoms immediately if they are experiencing concussion-like symptoms, to RTP faster and to mitigate potentially negative effects of physical exertion or additional head impacts within this “window of vulnerability.”

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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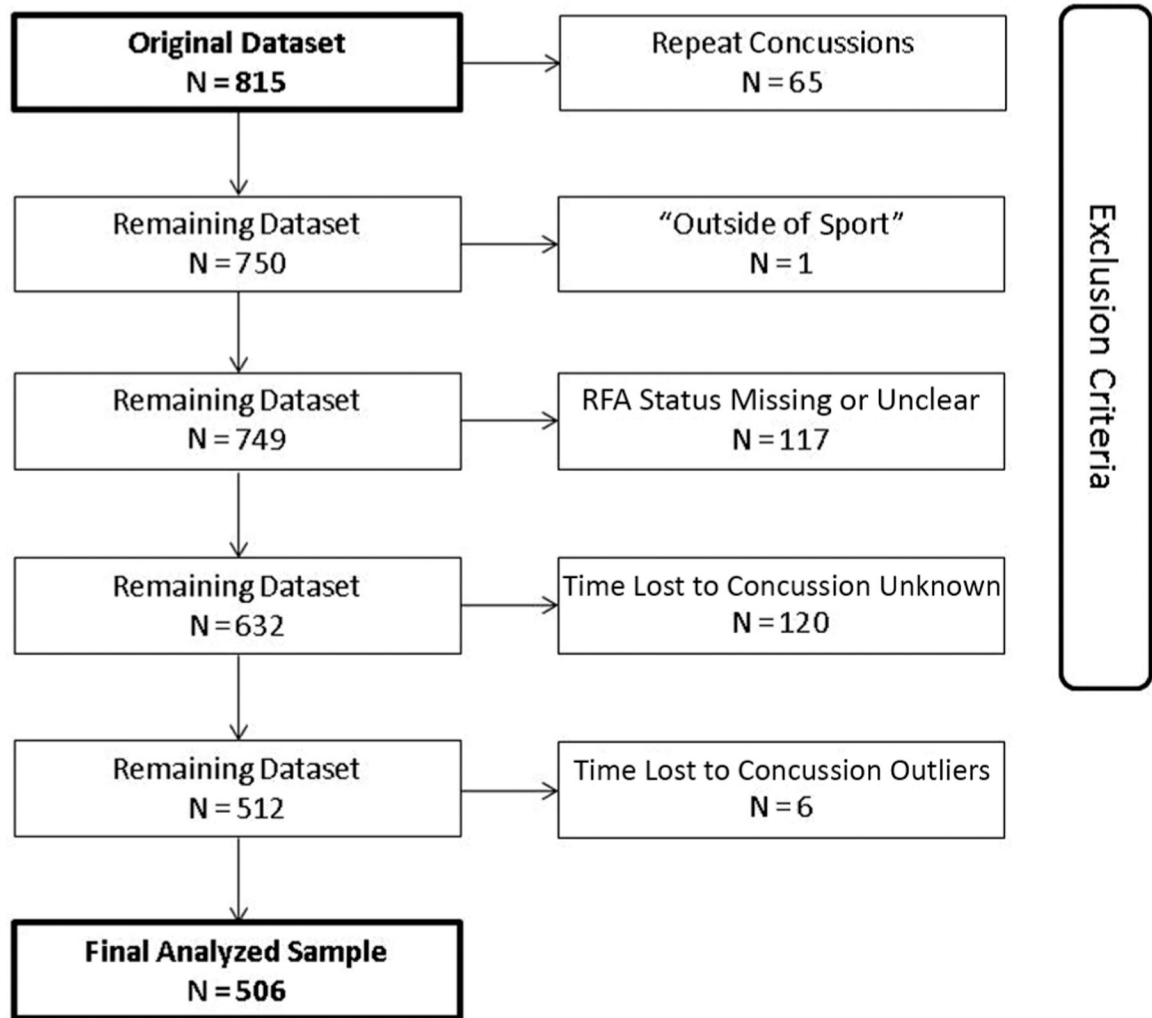
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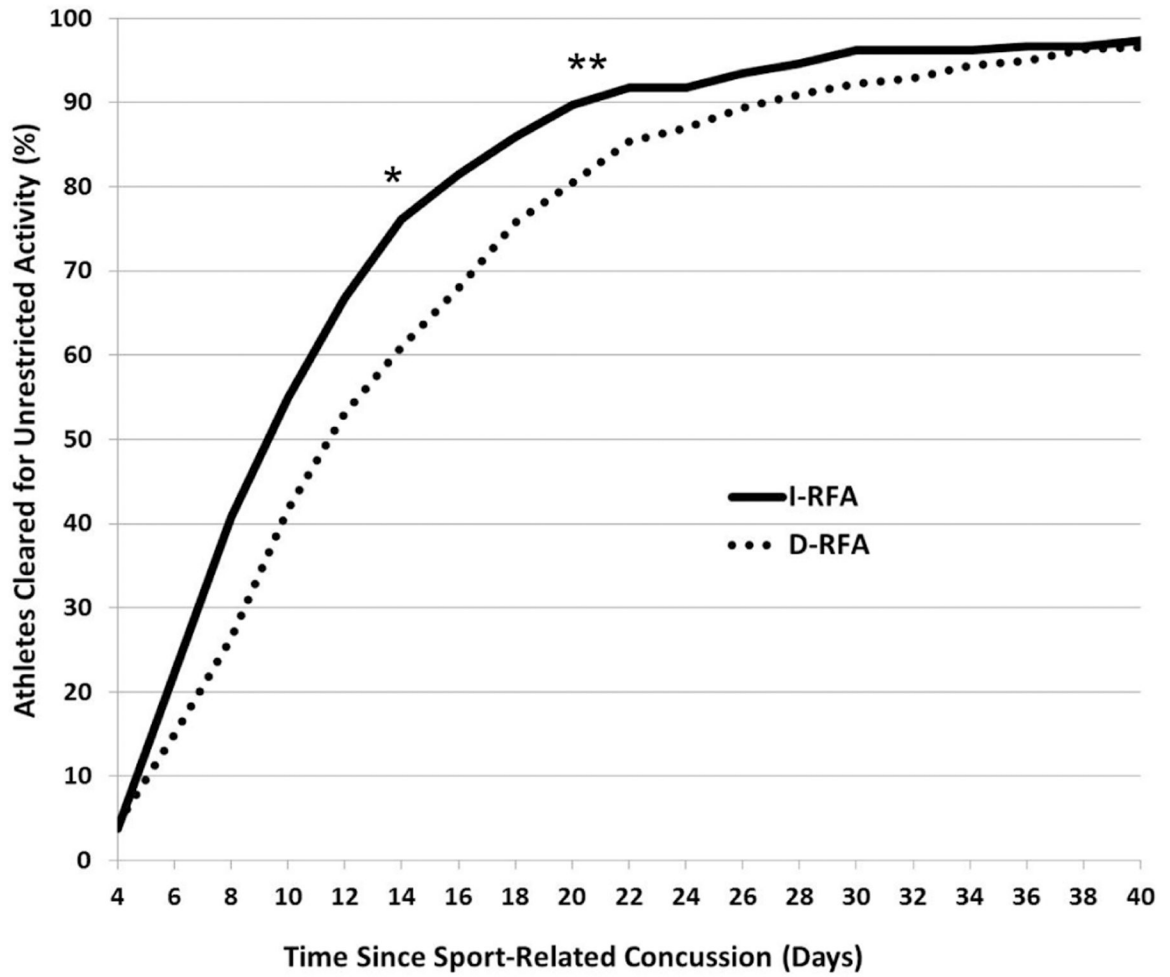
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**Figure 1.**

Process of case removal from the initial sport-related concussion data set before analyses and subsequent outlier removal (time lost to concussion  $>3$  SD above sample mean). RFA, removal from activity.





**Figure 2.** Recovery trajectories of the percentage of athletes achieving full medical clearance based on the number of days after a sport-related concussion: I-RFA vs D-RFA. \*I-RFA group at 39% lower likelihood of missing 14 days (relative risk = 0.614,  $P < .001$ ). \*\*I-RFA at 47% lower likelihood of missing 21 days (relative risk = 0.534,  $P = .010$ ). D-RFA, delayed removal from activity; I-RFA, immediate removal from activity.

**TABLE 1**

Classification of Athletes Into I-RFA (n = 184) or D-RFA (n = 322) and Associated Sample Sizes<sup>a</sup>

	"Did the Athlete Immediately Report the Injury?"			
	"Was the Athlete Immediately Removed From Play?"	Yes	No	NA
Yes	I-RFA (n = 184)	D-RFA (n = 34)	—	—
No	D-RFA (n = 39)	D-RFA (n = 217)	D-RFA (n = 13)	—
NA	—	D-RFA (n = 19)	—	—

<sup>a</sup>Based on 2 clinician-completed questions regarding removal from play after sport-related concussion. D-RFA, delayed removal from activity; I-RFA, immediate removal from activity; NA, not applicable.

**TABLE 2**

Sample Demographics and Prevalence of Covariates Stratified by RFA Group<sup>a</sup>

Factor	RFA Group, n (% of Group)			χ <sup>2</sup>	P Value	Missing, n (%)
	Immediate (n = 184)	Delayed (n = 322)	Total, n (% of Sample)			
Noninjury related						
Sex				0.011	.918	2 (0.3)
Men	113 (61.4)	198 (61.5)	311 (61.5)			
Women	71 (38.6)	122 (38.5)	193 (38.5)			
LD or ADHD	27 (14.7)	43 (13.4)	70 (13.8)	0.171	.679	0 (0.0)
Psych	8 (4.3)	24 (7.5)	32 (6.3)	1.906	.167	0 (0.0)
Migraines	23 (12.8)	30 (9.6)	53 (10.8)	1.290	.256	13 (2.6)
Concussion history <sup>b</sup>				3.919	.270	11 (2.2)
0	85 (47.0)	174 (55.4)	259 (52.3)			
1	71 (39.2)	97 (30.9)	168 (33.9)			
2	18 (9.9)	31 (9.9)	49 (9.9)			
3+	7 (3.9)	12 (3.8)	19 (3.8)			
Baseline, mean ± SD						
SCAT3	4.7 ± 8.0	5.5 ± 8.8		<i>t</i> = 0.979	.328	25 (4.9)
BSI-18	2.4 ± 4.2	3.0 ± 4.9		<i>t</i> = 1.39	.165	20 (4.0)
Injury related						
LOC	16 (8.7)	9 (2.8)	25 (5.0)	8.566	.003 <sup>c</sup>	5 (1.0)
AOC	113 (62.8)	128 (40.5)	241 (48.6)	22.771	<.001 <sup>c</sup>	9 (1.8)
Amnesia	30 (16.3)	42 (13.0)	72 (14.2)	1.020	.312	0 (0.0)
Sport <sup>d</sup>						
Football	56 (33.5)	111 (66.5)	167 (33.0)			
Soccer	39 (50.0)	39 (50.0)	78 (15.4)			
Basketball	22 (34.9)	41 (65.1)	63 (12.5)			
Lacrosse	11 (28.2)	28 (71.8)	39 (7.7)			
Water polo	8 (34.8)	15 (65.2)	23 (4.5)			
Volleyball	7 (35.0)	13 (65.0)	20 (4.0)			

Factor	RFA Group, n (% of Group)			Total, n (% of Sample)	$\chi^2$	P Value	Missing, n (%)
	Immediate (n = 184)	Delayed (n = 322)					
Gymnastics	6 (31.6)	13 (68.2)	19 (3.8)				
Ice hockey	3 (23.1)	10 (76.9)	13 (2.6)				
Other <sup>e</sup>	32 (38.6)	51 (61.4)	83 (16.4)				

<sup>a</sup>ADHD, attention-deficit/hyperactivity disorder; AOC, alteration of consciousness; BSI-18, Brief Symptom Inventory (18 items); LD, learning disability; LOC, loss of consciousness; Psych, diagnosed depression or other psychiatric diagnosis; RFA, removal from activity; SCAT3, Sport Concussion Assessment Tool–Third Edition symptom severity score.

<sup>b</sup>Concussion history remained a continuous variable within the linear regression analyses (range, 0–6).

<sup>c</sup> $P < .05$ .

<sup>d</sup>Percentages within the RFA group columns represent the percentage of athletes within that sport who had either immediate or delayed RFA (eg, 33.5% of the football participants in the study had immediate removal, and 66.5% had delayed removal). The percentage in the last column represents the proportion of the overall sample per sport (eg, football participants represented 33.0% of the overall sample).

<sup>e</sup>Other sports: swimming (n = 13), softball (n = 13), wrestling (n = 12), baseball (n = 8), field hockey (n = 7), rowing/crew (n = 7), cross-country/track (n = 6), tennis (n = 4), and cheerleading (n = 2).

**TABLE 3**

Unadjusted Descriptive Statistics of All Outcome Variables<sup>a</sup>

Clinical Outcome	n (% D-RFA)	RFA Group, Mean ± SD		Test Statistic	P Value	Effect Size, <i>d</i>
		Immediate	Delayed			
Time lost to concussion, d	506 (63.6)	12.0 ± 8.2	14.7 ± 9.8	$\beta = 0.154-0.161$	.001 <sup>b</sup>	
Duration of symptoms, d	429 (63.6)	4.8 ± 3.7	6.8 ± 5.2	$\beta = 0.217-0.223$	<.001 <sup>b</sup>	
Time 1 (0–6 h)						
SCAT3 symptom total	318 (51.6)	10.1 ± 4.9	11.8 ± 5.4	5.080 <sup>c</sup>	.003 <sup>d</sup>	.330
SCAT3 symptom severity		26.3 ± 19.3	31.5 ± 20.9		.024 <sup>d</sup>	.259
SAC	323 (51.7)	26.3 ± 2.9	26.1 ± 3.0	0.765 <sup>e</sup>	.445	.068
BESS	246 (48.4)	16.2 ± 8.3	16.9 ± 9.0	-0.505 <sup>e</sup>	.614	.081
Time 2 (24–48 h)						
SCAT3 symptom total	232 (53.9)	8.4 ± 5.8	10.6 ± 6.4	4.319 <sup>c</sup>	.009 <sup>d</sup>	.360
SCAT3 symptom severity		19.3 ± 20.2	25.6 ± 22.7		.027 <sup>d</sup>	.293
BSI-18		4.3 ± 5.7	7.1 ± 8.0		.002 <sup>d</sup>	.403
SAC	248 (52.8)	26.9 ± 2.5	26.4 ± 2.4	1.393 <sup>e</sup>	.165	.204
BESS	236 (53.4)	12.9 ± 6.6	14.7 ± 8.1	-1.860 <sup>e</sup>	.064	.244

<sup>a</sup>BESS, Balance Error Scoring System; BSI-18, Brief Symptom Inventory (18 items); D-RFA, delayed removal from activity; RFA, removal from activity; SAC, Standardized Assessment of Concussion; SCAT3, Sport Concussion Assessment Tool—Third Edition.

<sup>b</sup>Significance value corresponds to the unique association of the RFA group and the associated clinical outcome, controlling for all other predictors in the final regression model.

<sup>c</sup>Multivariate analysis of variance (Pillai trace *F*-statistic) with the RFA group as the fixed factor and with clinical symptom assessments for each time point as the dependent variables.

<sup>d</sup>Significance value corresponds to univariate group comparison.

<sup>e</sup>Independent samples *t* test.