Published in final edited form as:

Am J Sports Med. 2016 April ; 44(4): 1040–1046. doi:10.1177/0363546515625045.

Physical Activity Level and Symptom Duration Are Not Associated After Concussion

David R. Howell, PhD[*,†,‡,§], **Rebekah C. Mannix, MD, MPH**[§,‖,¶], **Bridget Quinn, MD**[‡], **J. Andrew Taylor, PhD**[#,**], **Can Ozan Tan, PhD**[#,**], and **William P. Meehan III, MD**[†,‡,§,‖,¶,††]

Sports Concussion Clinic, Division of Sports Medicine, Department of Orthopaedics, Boston Children's Hospital, Boston, Massachusetts, USA

Abstract

Background—Physical rest after a concussion has been described as a key component in the management of the injury. Evidence supporting this recommendation, however, is limited.

Purpose—To examine the association between physical activity and symptom duration in a cohort of patients after a concussion.

Study Design—Cohort study; Level of evidence, 2.

Methods—This study included 364 patients who were diagnosed with a concussion, were seen by a physician within 3 weeks of injury, and completed a questionnaire at the initial clinic visit. The questionnaire assessed the postconcussion symptom scale (PCSS) score, previous number of concussions, presence of the loss of consciousness or amnesia at the time of injury, and prior treatment for headaches. During each follow-up clinic visit, physical activity level was self-reported. A Cox proportional hazard model was constructed to determine the association between symptom duration, initial clinic visit responses, and self-reported physical activity level after the injury.

Results—Study participants ranged in age from 8 to 27 years (mean age, 15.0 years) and had sustained a mean of 0.8 prior concussions; 222 patients (61%) were male. On initial examination, the mean PCSS score was 34.7. The mean symptom duration was 48.9 days after the injury. Among the variables included in the model, initial PCSS score and female sex were independently

[*]Address correspondence to David R. Howell, PhD, The Micheli Center for Sports Injury Prevention, 9 Hope Avenue, Suite 100, Waltham, MA 02453, USA (David.Howell2@childrens.harvard.edu).
[†]The Micheli Center for Sports Injury Prevention, Waltham, Massachusetts, USA.
[‡]Sports Concussion Clinic, Division of Sports Medicine, Department of Orthopaedics, Boston Children's Hospital, Boston, Massachusetts, USA.
[§]Brain Injury Center, Boston Children's Hospital, Boston, Massachusetts, USA.
[‖]Division of Emergency Medicine, Boston Children's Hospital, Boston, Massachusetts, USA.
[¶]Department of Pediatrics, Harvard Medical School, Harvard University, Boston, Massachusetts, USA.
[#]Cardiovascular Research Laboratory, Spaulding Hospital Cambridge, Cambridge, Massachusetts, USA.
[**]Department of Physical Medicine and Rehabilitation, Harvard Medical School, Harvard University, Boston, Massachusetts, USA.
[††]Department of Orthopaedics, Harvard Medical School, Harvard University, Boston, Massachusetts, USA.

One or more of the authors has declared the following potential conflict of interest or source of funding: W.P.M. receives publishing royalties from ABC-Clio and Wolters Kluwer. He is under contract with ABC-Clio for a future book entitled *Concussions* and with Springer International for a future book entitled *Head and Neck Injuries in Young Athletes*. His research is funded in part by a grant from the National Football League Players Association and by philanthropic support from the National Hockey League Alumni Association through the Corey C. Griffin Pro-Am Tournament.

associated with symptom duration, while physical activity level after the injury was not. For participants aged between 13 and 18 years, however, higher levels of physical activity after the injury were associated with a shorter symptom duration.

Conclusion—Results from this study indicate that physical activity after the injury may not be universally detrimental to the recovery of concussion symptoms.

Keywords

brain concussion; mild traumatic brain injury; physical activity; rehabilitation

---

The clinical presentation and aftercare of sport-related concussions can be complex, multifaceted, and often controversial.[9] Prior research has commented on concussion incidence rates,[35] diagnostic techniques,[19] and the time course of symptom recovery after the injury.[28] Few studies, however, have prospectively assessed how behavior after an injury affects patient outcomes. Currently, the Consensus Statement on Concussion in Sport recommends a period of physical and cognitive rest immediately after concussions until cleared by a qualified health care professional to begin a stepwise return-to-play protocol, which gradually reintroduces physical activity as tolerated by the patient.[27] Additionally, in all 50 states of the United States, legislation intended to protect high school athletes from returning to sports too soon after head trauma has been enacted.[12]

Some have argued that, acutely after a concussion, unrestricted physical activity may be detrimental to recovery.[3] Previous investigations reported that a premature return to physical activity after concussions was related to increased concussion symptoms[6] and that postural stability on return to play was not fully recovered.[34] Another study observed that the resumption of unrestricted physical activity negatively affected dual-task gait balance control without affecting symptom severity or cognitive function.[18] Conversely, complete avoidance of physical activity may negatively affect recovery from a concussion: lack of physical activity has been documented to increase anxiety and depression and to lower self-esteem in a sample of athletes who sustained a sport-related injury.[23] In a recent randomized trial, Thomas et al[38] observed that strict cognitive and physical rest for 5 days after a concussion negatively affected symptom scores and duration when compared with the standard care of 2 days of rest followed by a gradual resumption of activity. Additionally, moderate levels of physical activity and cognitive activity after a concussion have been associated with better neurocognitive performance and lower symptom burdens than high activity levels.[24]

Thus, the relationship between physical activity after a concussion and symptom duration remains unclear. A further examination is necessary to determine the interaction between physical activity after a concussion and ultimate symptom recovery. In addition, if physical activity proves to be safe or even beneficial during recovery, the proper timing and optimal intensity of training need to be investigated. We conducted a prospective cohort study of patients reporting to a sport concussion clinic to determine the association between physical activity and symptom recovery after a concussion.

METHODS

Participants and Design

We conducted a prospective cohort study of patients presenting to a sport concussion clinic between October 1, 2009 and July 31, 2011. We included all patients who sustained a concussion during sports or by a mechanism involving forces similar to sports, such as falling from the ground level or being injured during recreational activities, which was diagnosed by a sports medicine physician. Patients with more severe injury mechanisms, such as falling from a height or being involved in motor vehicle collisions, were excluded. In addition, patients were excluded if they did not have complete medical records, were being considered for an alternate diagnosis at the time of assessment, were not examined within the first 21 days after injury, were not experiencing any symptoms at the time of the initial examination, or did not complete the questionnaires. We used the definition of a concussion provided by the Consensus Statement on Concussion in Sport: a complex pathophysiological process resulting from traumatic biomechanical forces imparted to the head, resulting in the onset of signs and/or symptoms of a concussion or changes in neurocognitive function.[27] Therefore, patients who experienced trauma to the head, resulting in the onset of signs and symptoms included in the postconcussion symptom scale (PCSS, described below),[27] were diagnosed with a concussion. All participants and parents/guardians (if < 18 years old) provided written informed consent to participate in the study. This study was approved by the institutional review board before commencement.

During the initial examination, standardized forms were completed by the patient, who reported demographic and clinical information. Data regarding the date of injury, mechanism of injury, loss of consciousness or amnesia at the time of injury, sport played at the time of injury, total number of prior concussions, and medical history were collected on the intake forms. Additionally, patients completed a symptom inventory, describing the severity of each symptom of the PCSS. If required, parents were available to help explain and answer concussion symptom ratings or other survey questions for younger patients.

Symptoms were assessed using the PCSS, a 22-symptom inventory adapted from the Standardized Concussion Assessment Tool version 2.[27] This scale uses a range of scores from 0 (asymptomatic) to 6 (maximum severity) for 22 typical symptoms of a concussion. Thus, possible PCSS scores range from a minimum of 0 to a maximum of 132. Previous research has used such symptom inventories to prospectively examine the effect of cognitive activity level on symptom duration,[5] the effect of returning to physical activity after concussions,[18] and the effect of activity level on symptom burden.[24] As patients without a concussion may endorse a certain level of symptoms,[4] participants were instructed to only rate those symptoms that started at the time of injury and those that they had been experiencing within 24 hours of the clinical assessment.[29,30] Symptom free was thus defined as a PCSS score of 0. Participants who were symptom free during their clinical examination recorded the last date on which they experienced symptoms. The time from the date of injury to the last date of symptoms was then calculated to determine the length of time for symptom duration for each participant. Although neurocognitive and balance assessments are often used in addition to symptom reporting to evaluate concussion recovery, these

variables were not measured in all participants at each clinical visit. Thus, we were unable to use these data to determine the exact duration of recovery or use them as covariates in our statistical model. Therefore, for our main outcome variable, we chose symptom duration, defined as the time (days) between the day of injury and the last day of symptoms.[21,24,29]

Activity was assessed during the initial clinic visit and during each regularly scheduled follow-up examination. During the initial clinic visit, patients were asked if they had continued regular exercise from the time of injury until the initial examination to assess the role of exercise acutely after a concussion. During follow-up visits, patients described their average level of physical activity (Table 1) and cognitive activity[5] since the previous clinic visit using standardized scales. This physical activity scale was adapted from the graduated return-to-play protocol described by the Consensus Statement on Concussion in Sport.[27] The ratings were completed by patients at each clinic visit as their average level since the time of their previous clinic visit. Ratings from this ordinal scale were used as time-varying covariates in subsequent statistical analyses.

Statistical Analysis

Continuous variables are presented as the mean ± SD; categorical variables are presented as percentages. To determine which variables were independently associated with symptom duration, a multivariate Cox proportional hazard model was constructed. In this model, the outcome variable was the total duration of concussion symptoms.

Based on prior literature suggesting an association with concussion recovery, the following variables were chosen as potential predictor variables: sex,[39] age as a continuous variable,[11,17] total number of previous concussions,[25] total PCSS score at the initial examination,[29,30] loss of consciousness at the time of injury,[2,26] amnesia at the time of injury,[8,26] prior treatment for headaches,[31] initial period of physical rest,[26,32] cognitive activity after the injury,[5,24] and physical activity after the injury.[18,22] Data on physical activity and cognitive activity were collected at each follow-up visit and entered into the statistical model at each time point as time-varying covariates. As the initial PCSS score has been identified as the strongest predictor of prolonged recovery,[29,30] we only included it as a measure of initial injury severity rather than the PCSS score at each clinic visit.

Before constructing the Cox regression model, potential predictor variables were assessed for collinearity using condition indices and corresponding variance inflation factors. A condition index greater than 30 was determined to require individual collinearity assessments, which were performed using variance inflation factors. Collinearity between 2 variables was detected with a variance inflation factor greater than 2.5. If this occurred, only 1 variable was included in the model.[30,36]

Furthermore, to compare the potential effect of age group on the duration of symptoms, we used univariate analysis of variance to compare the mean symptom duration for the following age groups: school age (≤12 years), junior high/high school age (13–18 years), and adult (≥19 years). To further examine how developmental stage may affect the association between physical activity and symptom duration, we then stratified patients into these age groups and constructed 3 separate Cox regression models using the same outcome

and predictor variables. Statistical significance was defined as a P value of <.05 or, for Cox regression models, a hazard ratio with a 95% CI that did not contain 1. Statistical analyses were performed with SPSS (version 21; IBM Corp) and Stata (version 11.2; StataCorp).

RESULTS

A total of 1050 patients received care in the sports concussion clinic during the study period and completed questionnaires. Of those, 686 were excluded: 466 because they did not report to the clinic within 21 days of injury, 84 because they did not report any concussion-related symptoms at the time of the initial visit, and 136 because they did not complete the physical and cognitive activity scales during their clinic visits. Thus, a total of 364 patients were included in the current study.

The mean time to presentation in the clinic after the injury was 11.8 ± 5.4 days. Patients ranged in age from 8 and 27 years with a mean age of 15.0 ± 2.8 years, were mostly (61%) male, and had sustained a mean of 0.8 ± 1.3 previous concussions before their current injury (Table 2). The majority of participants sustained their concussions during collision or contact sports (Table 3), while 38 participants reported sustaining their concussion in an activity other than sports. At the initial examination, participants reported a mean overall PCSS score of 34.7 ± 25.7 (see Appendix 1, available online at http://ajsm.sagepub.com/supplemental). Of those who reported a resolution of symptoms (68%), the mean symptom duration was 48.9 ± 76.0 days. Data on the symptom resolution date were not available for the remaining 32% of patients; these data were included as censored data in the multivariate Cox regression model. The majority (76%) of participants reported a period of physical rest between the time of injury and the initial examination (Table 4). The mean symptom duration was not significantly different between school-aged (46 ± 87 days), junior high/high school–aged (50 ± 77 days), or adult (38 ± 57 days) participants (P = .786) or between female (49 ± 108 days) and male patients (39 ± 80 days) (P = .431).

Significant collinearity was detected between self-reported physical activity and cognitive activity levels after the injury (variance inflation factor = 4.54). Additionally, the association between cognitive activity and symptom duration has been previously reported.[5] Thus, only physical activity was included as a time-varying covariate in the Cox regression model. Total PCSS score at the initial clinic visit and female sex were each independently associated with a longer duration of symptoms (see Appendix 2, available online). Participant age, number of previous concussions reported, loss of consciousness, amnesia, and prior treatment for headaches were not independently associated with the duration of symptoms. In addition, neither an initial period of physical inactivity from the time of injury until the first examination nor the amount of physical activity between the time of injury and each clinic visit had an independent association with the duration of symptoms (Appendix 2).

Cox regression analyses for age subgroups revealed that for adolescents of junior high/high school age, higher levels of physical activity after the injury, lower initial PCSS score, and male sex were associated with a shorter symptom duration (Appendix 2). For adults, a lower initial PCSS score was associated with a shorter symptom duration, while no significant associations were found within the school age subgroup (Appendix 2).

DISCUSSION

Data from our investigation suggest that physical activity after a concussion, at least at the levels self-selected by these patients reporting to a sport concussion clinic, is not independently associated with symptom duration. Further examination of adolescent participants, however, indicates that higher levels of physical activity after the injury are associated with a shorter duration of concussion symptoms. These findings extend previous work examining symptom duration after concussions and factors that are associated with prolonged recovery.[5,29,30] Avoidance of physical activity or relative physical rest until acute symptom resolution has been described as the current best practice of concussion management.[27] The goal of relative physical rest after concussions is to avoid symptom exacerbation. A prior retrospective study has observed that a premature return to contact sports may be associated with a recurrence of symptoms.[6] However, it remains unclear as to whether physical activity outside participation in contact sports is detrimental to recovery after a concussion.

The level of physical activity after a concussion may be an important consideration in management decisions. Previously, high levels of physical activity and cognitive activity during the first month after a concussion have been reported to be associated with worse symptom severity and neurocognitive performance than moderate activity levels.[24] However, the precise duration of physical rest required after concussions and the proper timing and intensity of reintegration into physical activities are considerations that remain poorly understood.[27] While returning to exercise before full recovery from a concussion has been associated with an increased symptom burden[6] and dual-task gait balance control deficits,[18] the lack of association between the amount of physical activity during the course of recovery and symptom duration among our entire cohort of participants suggests that some amount of physical activity may be acceptable during recovery from concussions. Furthermore, for adolescents specifically, higher levels of physical activity were associated with a faster symptom resolution time, while such an association was not found for older or younger age groups. This indicates that physical activity may affect symptom recovery throughout each stage of development differently and that adolescents may benefit from some physical activity to decrease symptom resolution time.

Prior work has investigated the effect of physical rest on concussion symptoms. Adolescents who underwent strict physical rest for the initial 5 days after a concussion had higher symptom severity over the first 10 days after a concussion than patients who underwent only a 1- to 2-day period of initial rest.[38] Thus, complete physical rest may not be an effective treatment strategy after concussions. This study employed a different methodological approach from ours by examining the acute effect of rest on concussion symptom severity, whereas we monitored physical activity throughout symptom resolution. Our data build on this prior work, however, as our data also suggest that physical activity after concussions is not detrimental to the length of time required to achieve symptom resolution, particularly among adolescent athletes.

Closely monitored physical activity represents one strategy that may potentially lead to decreased symptom severity. Previous data show that patients suffering from a traumatic

brain injury who exercise are less depressed, report fewer symptoms, and have a better health status than nonexercising patients.[14] Furthermore, cerebrovascular dysfunction[1,7,33] due to vascular damage[13] may, at least partly, underlie concussion symptoms such as altered cognitive function, headache, or dizziness. There is evidence to suggest that exercise at mild-to-moderate intensities may improve cerebrovascular function.[37] Thus, it is possible that controlled exercise could modify the concussion symptom burden through an improvement in cerebral autoregulation.[22]

It should also be noted that, particularly in the athletic population, a lack of physical activity may lead to deconditioning, which can induce physiological changes in the cerebral and systemic control of blood flow. Impaired cerebrovascular function has been documented after deconditioning caused by sustained head-down bed rest,[40] and even a single day of bed rest has been reported to reduce cerebral blood flow for the subsequent 4 to 5 hours.[20] Cardiovascular-autonomic dysfunction has also been identified in a cohort of patients with a history of mild traumatic brain injury, noted by lower supine heart rate variability and less responses to standing.[15] Thus, those who continue to engage in physical rest beyond the acute phase of concussion recovery may be at risk for deconditioning, which may lead to a longer duration of time required for symptom resolution. The participants within this study were primarily athletes, so the addition of physical activity after a concussion may also represent a return to normal everyday life. As athletes who miss time due to injury may be more likely to exhibit depression or anxiety,[23] 2 symptoms also associated with concussions, some physical activity for this population may constitute a potential treatment to assist with the reduction of emotional symptoms.

Our finding that a high initial symptom burden was associated with a longer duration of symptoms supports previous work.[5,29,30] Our results also suggest that female patients may be at a greater risk for symptom persistence after concussions, and this relative risk was greater than the initial symptom burden variable. This is consistent with reports that female patients have greater cognitive deficits after concussions than their male counterparts,[10] but other previous studies have not revealed a consistent sex bias.[5,29,30] Furthermore, Brown and colleagues[4] have recently identified that the symptomatic presentation of female patients significantly differs from that of male patients in which female patients reported more symptoms both at baseline and after a concussion. Thus, while initial symptom burden may be among the best predictors of a prolonged symptom duration,[29] female patients may also possess a greater risk for symptom persistence after concussions than male patients.

The interpretation of the findings from this study must be viewed in light of several limitations. All study participants reported to a specialty concussion clinic and therefore likely represent a different cohort that is perhaps more severe than the general population of athletes who sustain concussions, thus limiting the generalizability of our results. This may be reflected in the mean symptom duration (~49 days), which is considerably longer than previous reports that identify that 98% of high school athletes report symptom recovery within 28 days of injury[28] and that adolescents require approximately 30 days after a concussion to return to similar symptom severities as a matched control group.[16] Neurocognitive, balance, and visual function assessments were not used to determine recovery from a concussion. Rather, self-reported symptom severity was used as a tool to

evaluate recovery. Although objective tools are also helpful in determining recovery, symptom reporting represents a highly feasible tool in assessing recovery from concussions that many health care professionals utilize to make management decisions. Additionally, we relied on patients' recall of self-reported activity level instead of a controlled exercise training program. Given the collinearity between cognitive activity and physical activity, we did not include cognitive activity in our model. Thus, our observations have not been adjusted for the effect of cognitive activity. Future prospective trials examining the effects of exercise training on pathophysiology and persistent concussion symptoms should employ a standardized exercise program. Finally, data regarding the symptoms and resolution times of prior concussions were not obtained and may have affected our results.

In conclusion, among a cohort of patients reporting to a sport concussion clinic, physical activity level after a concussion was not independently associated with symptom duration, suggesting that physical activity may not be universally detrimental to the recovery of concussion symptoms. These findings warrant further investigation regarding the effects of physical activity after the injury on recovery from concussions. In particular, the effects of intensity level and timing of physical activity on recovery from a concussion should be further explored.

References

1. Bailey DM, Jones DW, Sinnott A, et al. Impaired cerebral haemodynamic function associated with chronic traumatic brain injury in professional boxers. Clin Sci Lond. 2013; 124(3):177–189. [PubMed: 22913765]
2. Bazarian JJ, Wong T, Harris M, Leahey N, Mookerjee S, Dombovy M. Epidemiology and predictors of post-concussive syndrome after minor head injury in an emergency population. Brain Inj. 1999; 13(3):173–189. [PubMed: 10081599]
3. Broglio SP, Collins MW, Williams RM, Mucha A, Kontos AP. Current and emerging rehabilitation for concussion: a review of the evidence. Clin Sports Med. 2015; 34(2):213–231. [PubMed: 25818710]
4. Brown DA, Elsass JA, Miller AJ, Reed LE, Reneker JC. Differences in symptom reporting between males and females at baseline and after a sports-related concussion: a systematic review and meta-analysis. Sports Med. 2015; 45(7):1027–1040. [PubMed: 25971368]
5. Brown NJ, Mannix RC, O'Brien MJ, Gostine D, Collins MW, Meehan WP. Effect of cognitive activity level on duration of post-concussion symptoms. Pediatrics. 2014; 133(2):e299–e304. [PubMed: 24394679]
6. Carson JD, Lawrence DW, Kraft SA, et al. Premature return to play and return to learn after a sport-related concussion: physician's chart review. Can Fam Physician. 2014; 60(6):e310–e315. [PubMed: 24925965]
7. Chan S, Tam Y, Lai C, et al. Transcranial Doppler study of cerebrovascular reactivity: are migraineurs more sensitive to breath-hold challenge? Brain Res. 2009; 1291:53–59. [PubMed: 19635466]
8. Collins MW, Iverson GL, Lovell MR, McKeag DB, Norwig J, Maroon J. On-field predictors of neuropsychological and symptom deficit following sports-related concussion. Clin J Sport Med. 2003; 13(4):222. [PubMed: 12855924]
9. Doolan AW, Day DD, Maerlender AC, Goforth M, Brolinson PG. A review of return to play issues and sports-related concussion. Ann Biomed Eng. 2012; 40(1):106–113. [PubMed: 21997390]
10. Dougan BK, Horswill MS, Geffen GM. Athletes' age, sex, and years of education moderate the acute neuropsychological impact of sports-related concussion: a meta-analysis. J Int Neuropsychol Soc. 2014; 20(1):64–80. [PubMed: 23375058]

11. Field M, Collins MW, Lovell MR, Maroon J. Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. J Pediatr. 2003; 142(5):546–553. [PubMed: 12756388]
12. Gibson TB, Herring SA, Kutcher JS, Broglio SP. Analyzing the effect of state legislation on health care utilization for children with concussion. JAMA Pediatr. 2015; 169(2):163–168. [PubMed: 25531065]
13. Giza CC, Hovda DA. The new neurometabolic cascade of concussion. Neurosurgery. 2014; 75(Suppl 4):S24–S33.
14. Gordon WA, Sliwinski M, Echo J, McLoughlin M, Sheerer MS, Meili TE. The benefits of exercise in individuals with traumatic brain injury: a retrospective study. J Head Trauma Rehabil. 1998; 13(4):58–67. [PubMed: 9651240]
15. Hilz MJ, DeFina PA, Anders S, et al. Frequency analysis unveils cardiac autonomic dysfunction after mild traumatic brain injury. J Neurotrauma. 2011; 28(9):1727–1738. [PubMed: 21355816]
16. Howell D, Osternig L, van Donkelaar P, Mayr U, Chou L-S. Effects of concussion on attention and executive function in adolescents. Med Sci Sports Exerc. 2013; 45(6):1030–1037. [PubMed: 23274602]
17. Howell DR, Osternig LR, Chou L-S. Adolescents demonstrate greater gait balance control deficits after concussion than young adults. Am J Sports Med. 2015; 43(3):625–632. [PubMed: 25540297]
18. Howell DR, Osternig LR, Chou L-S. Return to activity after concussion affects dual-task gait balance control recovery. Med Sci Sports Exerc. 2015; 47(4):673–680. [PubMed: 25100340]
19. Jeter CB, Hergenroeder GW, Hylin MJ, Redell JB, Moore AN, Dash PK. Biomarkers for the diagnosis and prognosis of mild traumatic brain injury/concussion. J Neurotrauma. 2013; 30(8): 657–670. [PubMed: 23062081]
20. Kawai Y, Murthy G, Watenpaugh DE, Breit GA, Deroshia CW, Hargens AR. Cerebral blood flow velocity in humans exposed to 24 h of head-down tilt. J Appl Physiol. 1993; 74(6):3046–3051. [PubMed: 8366006]
21. Leddy JJ, Cox JL, Baker JG, et al. Exercise treatment for postconcussion syndrome: a pilot study of changes in functional magnetic resonance imaging activation, physiology, and symptoms. J Head Trauma Rehabil. 2013; 28(4):241–249. [PubMed: 23249769]
22. Leddy JJ, Kozlowski K, Donnelly JP, Pendergast DR, Epstein LH, Willer B. A preliminary study of subsymptom threshold exercise training for refractory postconcussion syndrome. Clin J Sport Med. 2010; 20(1):21–27. [PubMed: 20051730]
23. Leddy MH, Lambert MJ, Ogles BM. Psychological consequences of athletic injury among high-level competitors. Res Q Exerc Sport. 1994; 65(4):347–354. [PubMed: 7886284]
24. Majerske CW, Mihalik JP, Ren D, et al. Concussion in sports: post-concussive activity levels, symptoms, and neurocognitive performance. J Athl Train. 2008; 43(3):265–274. [PubMed: 18523563]
25. McCrea M, Guskiewicz K, Marshall S, et al. Acute effects and recovery time following concussion in collegiate football players: the NCAA concussion study. JAMA. 2003; 290(19):2556–2563. [PubMed: 14625332]
26. McCrea M, Guskiewicz K, Randolph C, et al. Incidence, clinical course, and predictors of prolonged recovery time following sport-related concussion in high school and college athletes. J Int Neuropsychol Soc. 2013; 19(1):22–33. [PubMed: 23058235]
27. McCrory P, Meeuwisse WH, Aubry M, et al. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport, Zurich, November 2012. J Athl Train. 2013; 48(4):554–575. [PubMed: 23855364]
28. Meehan WP, d'Hemecourt P, Collins CL, Comstock RD. Assessment and management of sport-related concussions in United States high schools. Am J Sports Med. 2011; 39(11):2304–2310. [PubMed: 21969181]
29. Meehan WP, Mannix RC, Monuteaux MC, Stein CJ, Bachur RG. Early symptom burden predicts recovery after sport-related concussion. Neurology. 2014; 83(24):2204–2210. [PubMed: 25381296]

30. Meehan WP, Mannix RC, Stracciolini A, Elbin RJ, Collins MW. Symptom severity predicts prolonged recovery after sport-related concussion, but age and amnesia do not. J Pediatr. 2013; 163(3):721–725. [PubMed: 23628374]
31. Morgan CD, Zuckerman SL, Lee YM, et al. Predictors of postconcussion syndrome after sports-related concussion in young athletes: a matched case-control study. J Neurosurg Pediatr. 2015; 15(6):589–598. [PubMed: 25745949]
32. Moser RS, Schatz P, Glenn M, Kollias KE, Iverson GL. Examining prescribed rest as treatment for adolescents who are slow to recover from concussion. Brain Inj. 2015; 29(1):58–63. [PubMed: 25279423]
33. Ocon AJ, Kulesa J, Clarke D, Taneja I, Medow MS, Stewart JM. Increased phase synchronization and decreased cerebral autoregulation during fainting in the young. Am J Physiol Heart Circ Physiol. 2009; 297(6):H2084–H2095. [PubMed: 19820196]
34. Powers KC, Kalmar JM, Cinelli ME. Recovery of static stability following a concussion. Gait Posture. 2014; 39(1):611–614. [PubMed: 23810088]
35. Rosenthal JA, Foraker RE, Collins CL, Comstock RD. National high school athlete concussion rates from 2005–2006 to 2011–2012. Am J Sports Med. 2014; 42(7):1710–1715. [PubMed: 24739186]
36. Simon, L. [Accessed March 4, 2015] Detecting multicollinearity using variance inflation factors. 2015. Available at: https://onlinecourses.science.psu.edu/stat501/node/347
37. Tan CO, Meehan WP, Iverson GL, Taylor JA. Cerebrovascular regulation, exercise, and mild traumatic brain injury. Neurology. 2014; 83(18):1665–1672. [PubMed: 25274845]
38. Thomas DG, Apps JN, Hoffmann RG, McCrea M, Hammeke T. Benefits of strict rest after acute concussion: a randomized controlled trial. Pediatrics. 2015; 135(2):213–223. [PubMed: 25560444]
39. Tsushima WT, Lum M, Geling O. Sex differences in the long-term neuropsychological outcome of mild traumatic brain injury. Brain Inj. 2009; 23(10):809–814. [PubMed: 19697169]
40. Zhang R, Zuckerman JH, Pawelczyk JA, Levine BD. Effects of head-down-tilt bed rest on cerebral hemodynamics during orthostatic stress. J Appl Physiol. 1997; 83(6):2139–2145. [PubMed: 9390992]

TABLE 1

Physical Activity Scale Ratings Completed by Participants at Each Visit to the Clinic[a]

Physical Activity Scale	Description
1 = rest	No athletic activity except walking.
2 = minimal athletic activity	Light aerobic activity such as vigorous walking or light stationary bicycle riding, such that you barely break a sweat.
3 = moderate athletic activity	Moderate aerobic activity such as jogging or brisk cycling, such that you are sweating but are able to carry on a conversation.
4 = sport-specific activity	Sport-specific or full aerobic activity such as running, ice skating, swimming, throwing, dribbling a ball, or cycling.
5 = noncontact activity only	Noncontact training drills such as passing, shooting, and/or resistance training such as push-ups, sit-ups, or weightlifting.
6 = full practice with contact	Full-contact practice, including contact.
7 = game play	You have been playing fully with the team.

[a]Ratings on this scale were adapted from the stages described in the graduated return-to-play protocol provided by the Consensus Statement on Concussion in Sport.[27]

TABLE 2

Demographic Data and Medical History of Participants[a]

Variable	Female (n = 142)	Male (n = 222)
School age (≤12 y)	13 (9)	48 (22)
Junior high/high school age (13–18 y)	113 (80)	160 (72)
Adult (≥19 y)	16 (11)	14 (6)
History of concussion	45 (32)	81 (36)
History of migraine	14 (10)	15 (7)
Treatment for headache before concussion	22 (16)	32 (14)
History of psychiatric condition	14 (10)	9 (4)
Learning disability	1 (1)	5 (2)
Loss of consciousness at time of injury	23 (16)	52 (23)
Amnesia at time of injury	44 (31)	92 (41)

[a]Data are reported as n (%).

TABLE 3

Sports Participation at the Time of Injury[a]

Sport	Female Athletes	Male Athletes	All Athletes
Ice hockey	23	20	21
Football	2	28	18
Basketball	15	14	14
Soccer	19	7	12
Lacrosse	4	6	5
Skiing/snowboarding	3	2	2
Wrestling	0	2	1
Cheerleading	4	0	1
Baseball	0	2	1

[a]Data are reported as percentages. Fewer than 5 patients reported sustaining a concussion while participating in the following sports: softball, field hockey, rugby, horseback riding, dance, running/track, swimming, diving, cycling, gymnastics, volleyball, and crew. Mechanisms of injury that occurred outside of sports included the following activities: color guard, physical education class, roughhousing, and slipping on ice.

TABLE 4

Descriptive Data for Activity Level and Symptom Severity at the Initial Clinic Visit and the First Follow-up Visit[a]

Variable	n (%)[b]	PCSS, Mean ± SD
Initial clinic visit		
Initial period of physical rest	278 (76)	36.2 ± 26.5
No initial period of physical rest	76 (21)	30.3 ± 23.3
First follow-up visit		
Physical activity level 1 (complete rest)	105 (29)	26.1 ± 28.7
Physical activity levels 2–3 (minimal/moderate)	113 (31)	10.5 ± 17.2
Physical activity levels 4–6 (sport-specific)	102 (28)	4.2 ± 8.6
Physical activity level 7 (full athletic activity)	16 (4)	1.4 ± 3.1

[a]PCSS, postconcussion symptom scale.

[b]Values may not add up to 364 patients or 100%, as not all participants recorded all responses.