Physical Maturity and Concussion Symptom Duration among Adolescent Ice Hockey Players

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Objective To investigate the association between physical maturity and risk of prolonged concussion symptoms in adolescent ice hockey players.

Study design Prospective cohort study of 145 patients ages 13-18 years with concussion referred to 3 hospital-affiliated sports medicine clinics between September 1, 2012 and March 31, 2015. Concussion evaluations included Post Concussive Symptom Score, neurologic examination, and postinjury computerized neurocognitive testing. Pubertal development at initial visit was assessed by the Pubertal Developmental Scale. Duration of concussion symptoms (days) was the main outcome. Statistical comparisons were conducted using Student *t* test, Wilcoxon rank sum, and logistic regression.

Results Mean symptom duration was 44.5 ± 48.7 days. Nearly one-half (48.3%) of all players enrolled had prolonged concussion symptoms (≥28 days); most (86.9%) had symptom resolution by 90 days. Among males, less physically mature adolescents took longer to recover than more physically mature players (54.5 days vs 33.4 days; $P = .004$). "Early" Pubertal Category Score was the strongest predictor of prolonged symptoms (OR = 4.29, 95% CI 1.24-14.85; $P = .021$) among males. Among females, heavier weight increased the odds of experiencing prolonged symptoms (OR 1.07, 95% CI 1.00-1.14; $P = .039$).

Conclusions Among adolescent ice hockey players, early-pubertal stage is independently associated with longer recovery from concussion in males, and heavier weight is associated with longer concussion recovery in females. Until further studies determine valid physical maturity indicators, peripubertal collision sport athletes should compete in leagues grouped by relative age and be discouraged from "playing up" on varsity teams. *(J Pediatr 2016;171:234-9)*.

Concussion has been reported to be the most common youth ice hockey injury, representing more than 15% of all injuries in 9- to 16-year-old players[1,2] and nearly 25% of injuries among boys' high school players.[3] Unlike other contact-collision scholastic sports with a high incidence of concussion, high school ice hockey lacks stratification by age grouping, largely because of prohibitive costs associated with equipment, transportation, and ice time incurred with fielding varsity, junior varsity (JV), and/or freshman teams.[4-6] Consequently, it is not uncommon at the varsity level for younger, less physically mature players to oppose older players with increased strength, power, and speed (**Video**; available at www.jpeds.com).

Even though it is documented that ice hockey players have the highest concussion rates of all collegiate sports,[7] there is a paucity of data in high school ice hockey. According to the National Federation of State High School Associations' Participation Survey, 17 states sanctioned high school ice hockey in 2012-2013, with nearly 45 000 boys and girls participating on high school teams.[8] Given the regional nature of high school ice hockey, concussion rates have historically been excluded from large high school epidemiologic studies, although recent studies have demonstrated that boys' ice hockey has a concussion incidence second only to boys' football.[3,9] Moreover, prior high school epidemiologic studies have neglected to investigate the unique scenario of scholastic ice hockey, one of the few sanctioned contact-collision sports in which underclassmen routinely compete against upperclassmen at the varsity level.

Although recent rule changes have been implemented in an effort to decrease contact to the head and neck, reduce risk of injury related to body checking, and encourage skill development at younger age levels in youth hockey,[10] body checking remains legal among male adolescents in youth and high school ice hockey.

JV	Junior varsity
PCSS	Post Concussion Symptom Score
PDS	Pubertal Development Scale

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A recent study comparing youth hockey in 2 Canadian provinces showed a 3-fold increased risk of all game-related injuries in the categories of concussion, severe injury (time loss >7 days), and severe concussion (time loss >10 days) in leagues that permitted body checking compared with leagues that prohibit body checking at the same age level.[11] These findings relating to concussion, coupled with previous studies reporting that smaller player size and lighter player weight independently are risk factors for injury in youth ice hockey,[11-13] and a recent study[14] reporting menarche as a risk factor for injury in female ice hockey players, led our research team to examine concussion in high school ice hockey. Although previous research has investigated risk of concussive injury within a given relative age group of youth hockey players,[11,15] to our knowledge, no research has prospectively investigated concussion injury of high school ice hockey players—a unique population that has participants between ages 13 and 18 years of age in varying stages of physical maturity. Therefore, we conducted a prospective cohort study of high school ice hockey players seen in 3 outpatient specialty concussion clinics to investigate the association between physical maturity and risk of prolonged concussion symptoms (≥28 days) and identify other potential predictors of prolonged concussion symptoms among ice hockey players aged 13-18 years old.

Methods

We included ice hockey players (males and females) age 13-18 years seen in outpatient sports concussion clinics at 3 regional medical centers, Rhode Island Hospital, Boston Children's Hospital, and South Shore Hospital (Weymouth, MA), with in-season concussions sustained during an ice hockey game or practice during the scholastic year (September-June). Average concussion visits per year at each institution are as follows: > 400 (Rhode Island Hospital), >3700 (Boston Children's Hospital), and >275 (South Shore Hospital). Players were excluded if they had a prior concussion within 6 months of presentation, had ≥3 prior diagnosed concussions, and, among high school ice hockey subjects, participated at a level other than varsity, as few New England public high schools field JV and/or freshman teams. Demographic, anthropometric, and injury data were collected at the time of the initial postconcussion evaluation and included age, year in school, weight, height, stage of pubertal development, player position, injury sustained in high school vs youth league play (Junior, Midget 18U, Midget 16U, Bantam 14U, and comparable female age categories—U19, U18, U16, U14), practice vs competition. Male players and female players were analyzed separately because: (1) pubertal developmental changes vary considerably between the sexes when compared with chronologic ages; and (2) only a minority of female players play boys' high school ice hockey or coed youth hockey in New England, resulting in different exposures between males and females, including exposure to body checking. Post Concussion Symptom Score (PCSS) was measured at initial and follow-up assessments using a standardized, 22-item concussion symptom list (7-point Likert scale graded 0-6 on severity).[16] Pre-injury, baseline (when available), and postinjury neurocognitive function was assessed with computerized neurocognitive testing (ImPACT) and used in decision-making regarding return to school and return to play for injured student-athletes. The main outcome variable was duration of concussion symptoms in days. Written informed consent and assent to participate was obtained. Institutional review board approval was granted from Rhode Island Hospital.

Concussion was defined according to the definition proposed by the International Conference on Concussion in Sport,[17] such that hockey players experiencing trauma to the head followed by the signs and symptoms of concussion included in the PCSS were diagnosed with a concussion. Symptom resolution was defined according to currently accepted criteria[18-20]; athletes were instructed to rate only those symptoms that started at their time of injury and were still present within 24 hours before clinic visit. Date of symptom resolution was defined as the day that the student-athlete self-reported no longer experiencing symptoms from their concussion. Time to symptom resolution (in days) following concussion was collected for males and females, and symptom duration was compared for each sex after dividing players into early and late stages of pubertal development. As prior studies have demonstrated that >90% of concussions in high school athletes competing in collision sports have resolved by 28 days,[16] the authors selected 28 days as the cutoff for prolonged concussion for the purpose of this study.

The Pubertal Development Scale (PDS), a validated puberty rating scale developed by Petersen et al[21] that allows self-assessment of 5 items of physical development (growth in height, body hair, skin changes, facial hair, and voice changes for boys; breast development and menses for girls) using a questionnaire rather than pictorial representations or physical examination, was completed for each study participant. A Puberty Category Score was computed using 3 indices of pubertal change determined by the rating scale developers to be most salient for each sex. Either "early" (pre-, early, and midpubescent) or "late" (advanced, postpubescent) pubertal development stages were assigned to each study participant. An in-depth summary of the PDS, an explanation of the Puberty Category Score computation, and an example of the PDS used in this study are provided in **Appendices 1** and **2** (available at www.jpeds.com).

Statistical Analyses

Continuous variables are presented as means ± SD and were compared using Student *t* test if normally distributed. Nonnormal data were compared using Wilcoxon rank sum and are presented as medians (IQR). Multivariate logistic regression analysis was performed to generate aORs demonstrating the association between risk of prolonged concussion symptoms and 7 predictor variables: age, weight, height, Puberty Category Score, PCSS, player

position, and year in school. Prior to analysis, the independent variables age, weight, and height were assessed for collinearity using a tolerance value of <0.10 and a variance inflation factor of >10 as cut-off points.[22] No collinearity was observed, as all tolerance values were 0.56 or greater, and all variance inflation factors were 1.86 or less. Data analysis was performed by using SPSS v 20.0 (SPSS Inc/IBM, Chicago, Illinois). *P* values of <.05 were considered statistically significant.

Results

Overall, 196 adolescent ice hockey players participated in the study. Complete data was collected on 145 players over 3 seasons (**Figure 1**; available at www.jpeds.com). Male (n = 101) and female (n = 44) hockey players were similar in age, but male players were, in general, taller, heavier, and at an earlier stage of pubertal development than female players (**Table I**).

The majority (63.4%) of players enrolled within 21 days of injury. Fifty-one percent reported they had sustained a prior concussion. The mean duration of concussion symptoms was 44.5 ± 48.7 days. Nearly one-half (48.3%) of players had concussion symptoms for ≥28 days, with 35.2% of players experiencing concussion symptoms for 28-90 days (**Figure 2**). Most (84.8%) concussions occurred during games. More than one-half (68.1%) of concussions were sustained by wings and centers.

Male Players (n = 101)

Male players in the "early" pubertal category had a longer symptom duration than those in the "late" pubertal category (54.5 vs 33.4 days, *P* = .004). Among the male players, weight, Puberty Category Score, and initial PCSS were each independently associated with symptoms for ≥28 days; "early" Pubertal Category Score had the strongest association with prolonged concussion symptoms (**Table II**). Heavier weight was associated with decreased odds of experiencing

Table I. Subgroups of adolescent ice hockey players

	Adolescent male ice hockey players (n = 101)			Adolescent female ice hockey players (n = 44)		
Player characteristics	**No. (%)**	**Mean ± SD**	**Range**	**No. (%)**	**Mean ± SD**	**Range**
Age (y)	-	15.4 ± 1.5	13.0-18.5	-	15.2 ± 1.4	13.1-18.1
Weight (lb)	-	145.8 ± 28.4	87.6-212.0	-	129.2 ± 26.7	80.9-205.5
Height (in)	-	67.6 ± 3.9	58.0-76.0	-	63.8 ± 4.4	51.5-74.6
PDS score	-	13.9 ± 3.5	4.0-20.0	-	17.2 ± 3.5	7.0-23.0
Low	67 (66.3)			8 (18.2)		
High	34 (33.7)			36 (81.8)		
Pubertal Category Score	-	8.3 ± 2.3	2.0-12.0	-	9.5 ± 2.4	5.0-12.0
Early	45 (44.6)			5 (11.4)		
Late	56 (55.4)			39 (88.6)		
Prior concussions						
None	49 (48.5)			22 (50.0)		
1	36 (35.6)			18 (40.9)		
2	16 (15.8)			4 (9.1)		
Level of play						
Varsity	34 (33.7)			25 (56.8)		
Middle School	1 (1.0)			-		
Travel						
Bantam (U14)	36 (35.6)			14 (31.8)		
Midget (U16)	12 (11.9)			1 (2.3)		
Midget (U18)	15 (14.9)			3 (6.8)		
(U19)	-			1 (2.3)		
Junior	3 (3.0)			-		
Girls only	-			42 (95.5)		
Co-ed	-			2 (4.5)		
Year in school						
7th grade	9 (8.9)			2 (4.5)		
8th grade	18 (17.8)			13 (30.2)		
Freshman	26 (25.7)			11 (25.0)		
Sophomore	22 (21.8)			8 (18.2)		
Junior	14 (13.9)			6 (13.6)		
Senior	12 (11.9)			4 (9.1)		
Position						
Center	17 (17.0)			4 (9.1)		
Wing	55 (55.0)			22 (50.0)		
Defense	23 (23.0)			12 (27.3)		
Goalie	5 (5.0)			6 (13.6)		
Exposure						
Game	90 (89.1)			33 (75.0)		
Practice	11 (10.9)			11 (25.0)		
Duration of symptoms (d)		42.8 ± 44.0	2.0-204.0		48.3 ± 58.5	4.0-324.0

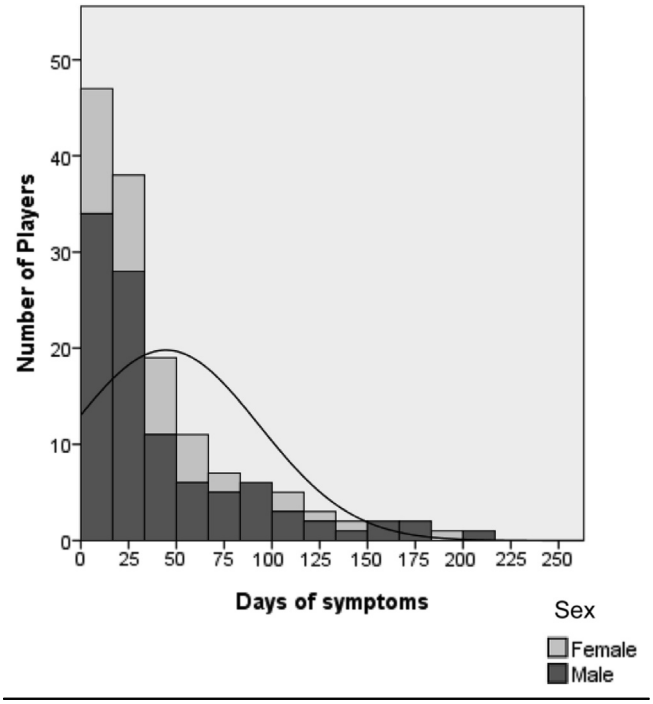

Figure 2. Duration of concussion symptoms among adolescent male and female ice hockey players, scholastic seasons 2012-2013 through 2014-2015. One U14 female player experienced symptoms for 324 days.

prolonged symptoms, and higher PCSSs on initial presentation were associated with increased odds of experiencing prolonged symptoms (Table II).

Among 74 male players attending high school (both scholastic and youth league players), 9/26 (34.6%) of freshman male ice hockey players had "late pubertal" self-assessment scores; none were postpubertal; 16/22 (72.7%) of sophomore, 12/14 (85.7%) of junior, and 12/12 (100%) of senior males had "late pubertal" self-assessment scores.

Female Players (n = 44)

More than one-half of female athletes played on the varsity team (Table I); nearly all (95.5%) played in girls only leagues. Most (88.6%) female players were in the "late" pubertal category, signified by achievement of menarche.

Table II. Adolescent male subgroup: Independent effect of potential predictor variables on odds of persistent concussive symptoms for more than 28 days

Potential predictor variables	aOR (95% CI)	*P* value
Age (y)	1.32 (0.61-2.88)	.484
Weight (lbs)	0.96 (0.93-0.99)	.008
Height (in)	1.14 (0.95-1.37)	.155
Pubertal Category Score (early vs late)	4.29 (1.24-14.85)	.021
PCSS	1.04 (1.01-1.06)	.003
Defense/goalie vs center/wing	0.49 (0.16-1.51)	.214
10th-12th grade vs 7th-9th grade	1.50 (0.17-13.69)	.718

Heavier weight increased the probability of experiencing prolonged concussion among females (aOR 1.07, 95% CI, 1.00-1.14 [Table III]). Female wings and centers were 5 times more likely to experience prolonged concussion than defensemen and goalies, a trend that approached but did not achieve statistical significance ($P = .097$).

Discussion

Using a validated pubertal development self-assessment scale to investigate disparities in age, size, and physical maturity level among adolescent ice hockey players with concussion, we found that pubertal development stage was independently associated with increased risk of prolonged symptoms from concussion among male adolescent ice hockey players. Our results indicate that pre-, early, and midpubescent males have a significantly longer duration of concussion symptoms compared with advanced and postpubescent males. Furthermore, lighter weight among males and heavier weight among females increased the probability of experiencing prolonged concussion.

Although our finding of lighter-weight males experiencing prolonged concussion is consistent with prior studies investigating risk factors for injury in youth ice hockey players,[11-13] our finding of heavier-weight females experiencing prolonged concussion is a novel result. Upon further investigation, our author group determined that in 2 of these 3 youth ice hockey studies, >98% and 100% of study participants were male, respectively.[11,12] Study demographics, including sex, were unable to be obtained for the third study.[13] As heavier-weight females experiencing prolonged concussion was an unexpected finding in our study and the aOR for heavier weight as an independent variable for adolescent females was only 1.07 (95% CI 1.00-1.14), it is quite possible that this result has more statistical than clinical significance.

In addition, our findings corroborate the concern expressed in prior sport-related concussion consensus and position statements' that adolescents might have longer recoveries from concussions than adults.[17,23-26] Overall, there is limited data regarding the typical duration of concussion symptoms in adolescent collision sport athletes. Collins et al[16] studied 136 high school football players 13-19 years old (mean age 15.9-16.3 years) who sustained concussions (pre- and in-season) over 3 seasons. The mean number of days to recover and return to play was between 10 and 13, and approximately 90% of players experienced recovery at 28 days. Field et al[27] studied 39 high school varsity athletes (35 football and 4 soccer players) 14-18 years old (mean age 15.9 years) who sustained concussions and found that when compared with matched control subjects as well as college athletes with concussion, these high school athletes had significant memory impairment for at least 7 days after injury; neuropsychological evaluation was not conducted beyond 7 days postinjury. Prior studies have examined age and weight as independent risk factors for injury in youth

Table III. Adolescent female subgroup: Independent effect of potential predictor variables on odds of persistent concussive symptoms for more than 28 days

Potential predictor variables	aOR (95% CI)	*P* value
Age (y)	0.38 (0.09-1.51)	.167
Weight (lb)	1.07 (1.00-1.14)	.039
Height (in)	0.77 (0.56-1.08)	.130
Pubertal Category Score (early vs late)	0.24 (0.07-8.73)	.436
PCSS	1.02 (0.97-1.07)	.442
Defense/goalie vs center/wing	4.99 (0.75-33.26)	.097
10th-12th grade vs 7th-9th grade	0.36 (0.01-10.44)	.555

ice hockey,[11-13] as well as the association between injury risk and physical maturity in youth American football and soccer.[28-30] The Consensus Statement on Concussion in Sport from the 4th International Conference on Concussion in Sport held in Zurich in 2012, which can be applied to adolescents 13 years and older according to its authors, states that the recovery of concussion occurs in a 7-10 day period in the majority of cases (80%-90%), although recovery may be longer in children and adolescents.[17]

Using a validated pubertal self-assessment questionnaire, we found that only 9/26 (34.6%) of freshman male ice hockey players had "late pubertal" self-assessment scores; none were postpubertal. Although the small size of this subgroup prevents reliable statistical analysis, these findings are nonetheless noteworthy, and prompt further research pertaining to the maturational status of adolescents participating in high school collision sports. Our results challenge recent expert opinion, which suggests collision sport participation be postponed until freshman year/age 14 years,[31] as 65.4% of freshman males were in early stages of pubertal development. Even though admittedly grade and age-based cut-offs are arbitrary, our results highlight the importance of future studies among peripubertal males to determine which measures (eg, bone age, % of predicted mature height, body mass index, pubertal self-assessment questionnaires) independently or collectively will reliably predict skeletal/physical maturity—a proposed marker for initiation of collision sport participation. Until results of such studies are available, our findings support a continued effort by state interscholastic leagues to provide peripubertal collision sport athletes competition in leagues grouped by relative age (eg, freshman, JV) and discourage the permission of highly skilled, peripubertal collision sport athletes to "play up" at the varsity level with postpubertal competitors 3-4 years their senior. Additionally, in accordance with recommendations from the American Academy of Pediatrics,[32] we encourage youth hockey organizations to provide the option of nonchecking divisions at the Bantam and Midget levels for players who remain in earlier stages of pubertal development, players who are undersized, players have significant concussion histories precluding them from participating in collision sport participation, or for players ≥13 years old seeking safer alternatives to body checking leagues.

Our study must be considered in light of several limitations. Only 44.1% of adolescent players enrolled within 10 days of their injury. This delay in presentation is common in specialty clinics, as the majority of patients are initially evaluated by athletic trainers, primary care physicians, emergency physicians, and urgent care providers, before being referred to subspecialty clinics for concussion management if symptoms persist. Thus, our study results may be less generalizable to community practices. In addition, although the Pubertal Developmental Scale questionnaire used in this study to estimate players' physical maturity status has shown agreement within one stage of pubertal development in 85%-100% of reported assessments,[33] most studies using self-administration of the PDS rather than an interview have generally been small and undertaken within clinic or home settings.[34] Finally, compared with other studies assessing concussion symptom duration in contact- and collision-sport adolescent athletes, our study population of ice hockey players experienced significantly longer concussion symptom durations. We attribute this finding to the association between referral patterns and specialty clinics, as over one-third (36.6%) of study participants presented >21 days from their injury. ■

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References

1. Emery CA, Meeuwisse WH. Injury rates, risk factors, and mechanisms of injury in minor hockey. Am J Sports Med 2006;34:1960-9.
2. Roberts WO, Brust JD, Leonard B. Youth ice hockey tournament injuries: rates and patterns compared to season play. Med Sci Sports Exerc 1999;31:46-51.
3. 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;39:2304-10.
4. Scherr R. Recent surge in popularity makes team ice hockey the hottest game around. http://articles.baltimoresun.com/1999-02-07/sports/9902070158_1_varsity-teams-varsity-status-maryland-interscholastic. Accessed August 31, 2015.
5. Straus B. Getting involved late, but sticking with it. http://www.washingtonpost.com/archive/local/2001/01/18/getting-involved-late-but-sticking-with-it/c03508ef-07eb-4dc3-ac2a-11e582f86b5f/. Accessed August 31, 2015.
6. Zimmer DM. Tis the season: West Milford school board approves hockey subsidy. Accessed, http://www.northjersey.com/news/education/boe-agrees-to-pay-additional-5k-for-ice-time-1.1178967; August 31, 2015.
7. Daneshvar DH, Nowinski CJ, McKee AC, Cantu RC. The epidemiology of sport-related concussion. Clin Sports Med 2011;30:1-17.
8. National Federation of High School Associations. 2012-13 high school athletics participation survey. http://www.nfhs.org/ParticipationStatics/ParticipationStatics.aspx/. Accessed May 31, 2015.
9. Marar M, McIlvain NM, Fields SK, Comstock RD. Epidemiology of concussions among United States high school athletes in 20 sports. Am J Sports Med 2012;40:747-55.
10. USA Hockey. USA Hockey official playing rules. Points of emphasis, 2011-12, 2012-13 playing seasons. USA Hockey website. http://assets.

ngin.com/attachments/document/0020/3167/2011-13_USA_Hockey_Rule_Change_Summary.pdf. Accessed May 31, 2015.
11. Emery CA, Kang J, Shrier I, Goulet C, Hagel B, Benson B, et al. Risk of injury associated with body checking among youth ice hockey players. JAMA 2010;303:2265-72.
12. Brust JD, Leonard BJ, Pheley A, Roberts WO. Children's ice hockey injuries. Am J Dis Child 1992;146:741-7.
13. Wiggins W. Implication of Introducing Body-Checking in Ice Hockey at Different Ages [master's thesis]. Thunder Bay, ON, Canada: Lakehead University; 1999.
14. Decloe MD, Meeuwisse WH, Hagel BE, Emery CA. Injury rates, types, mechanisms and risk factors in female youth ice hockey. Br J Sports Med 2014;48:51-6.
15. Emery CA, Kang J, Shrier I, Goulet C, Hagel B, Benson B, et al. Risk of injury associated with bodychecking experience among youth ice hockey players. CMAJ 2011;183:1249-56.
16. Collins M, Lovell MR, Iverson GL, Ide T, Maroon J. Examining concussion rates and return to play in high school football players wearing newer helmet technology: a three-year prospective cohort study. Neurosurgery 2006;58:275-86.
17. McCrory P, Meeuwisse WH, Aubry M, Cantu B, Dvorak J, Echemendia RJ, et al. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. Br J Sports Med 2013;47:250-8.
18. Babcock L, Byczkowski T, Wade SL, Ho M, Mookerjee S, Bazarian JJ. Predicting postconcussion syndrome after mild traumatic brain injury in children and adolescents who present to the emergency department. JAMA Pediatr 2013;167:156-61.
19. Meehan WP III, 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;163:721-5.
20. Meehan WP III, Mannix R, Monuteaux MC, Stein CJ, Bachur RG. Early symptom burden predicts recovery after sport-related concussion. Neurology 2014;83:2204-10.
21. Petersen AC, Crockett L, Richards M, Boxer A. A self-report measure of pubertal status: reliability, validity, and initial norms. J Youth Adolesc 1988;17:117-33.
22. Pallant J. SPSS survival manual: A step by step guide to data analysis using SPSS. 4th ed. Maidenhead: Open University Press/McGraw-Hill; 2010.
23. Giza CC, Kutcher JS, Ashwal S, Barth J, Getchius T, Gioia GA, et al. Summary of evidence-based guideline update: evaluation and management of concussion in sports: report of the Guideline Development Subcommittee of the American Academy of Neurology. Neurology 2013;80:2250-7.
24. Harmon KG, Drezner JA, Gammons M, Guskiewicz KM, Halstead M, Herring SA, et al. American Medical Society for Sports Medicine position statement: concussion in sport. Br J Sports Med 2013;47:15-26.
25. Sports-Related Concussions in Youth: Improving the Science, Changing the Culture. Committee on Sports-Related Concussions in Youth; Board on Children, Youth and Families; Institute of Medicine; National Research Council; Graham R, Rivara FP, Ford MA, Spicer CM, eds. Washington (DC): National Academies Press (US); 2014 Feb. http://www.iom.edu/Reports/2013/Sports-Related-Concussions-in-Youth-Improving-the-Science-Changing-the-Culture.aspx. Accessed May 31, 2015.
26. Halstead ME, Walter KD , Council on Sports Medicine and Fitness. American Academy of Pediatrics. Clinical report—sport-related concussion in children and adolescents. Pediatrics 2010;126:597-615.
27. 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;142:546-53.
28. Malina RM, Morano PJ, Barron M, Miller SJ, Cumming SP, Kontos AP. Incidence and player risk factors for injury in youth football. Clin J Sport Med 2006;16:214-22.
29. Linder MM, Townsend DJ, Jones JC, Balkcom IL, Anthony CR. Incidence of adolescent injuries in junior high school football and its relationship to sexual maturity. Clin J Sport Med 1995;5:167-70.
30. Le Gall F, Carling C, Reilly T. Biological maturity and injury in elite youth football. Scand J Med Sci Sports 2007;17:564-72.
31. Aspen Institute. Playing safety: the future of youth football? Roundtable discussion. November 9, 2012. http://www.aspeninstitute.org/sites/default/files/content/docs/sports/playing_safety_110912_transcript.pdf. Accessed May 31, 2015.
32. Council on Sports Medicine and Fitness Brooks A, Loud KJ, Brenner JS, Halstead ME, Kelly AK, Koutures CG, et al. Reducing injury risk from body checking in boys' youth ice hockey. Pediatrics 2014;133:1151-7.
33. Schmitz KE, Hovel MF, Nichols JF, Irvin VL, Keating K, Simon GM, et al. A validation study of early adolescents' pubertal self-assessments. J Early Adolesc 2004;24:357-84.
34. Bond L, Clements J, Bertalli N, Evans-Whipp T, McMorris BJ, Patton GC, et al. A comparison of self-reported puberty using the Pubertal Development Scale and the Sexual Maturation Scale in a school-based epidemiologic survey. J Adolesc 2006;29:709-20.

Appendix 1

Pubertal Development Scale

The Pubertal Development Scale (PDS) is an adaptation of an interview-based puberty rating scale developed by Petersen et al[1] for use in school-based early adolescent studies. The reliability and validity of this scale to measure adolescent's pubertal status without invasive techniques or pictorial representations has been assessed by multiple studies and investigators.[2-6] Although exact agreement between adolescents and physicians for Tanner staging and the PDS has been moderate (45%-81%) with 2 exceptions (86%-93% by Duke et al[7]; 27% for male genital development by Schlossberger et al[8]), agreement within one stage has been excellent (85%-100%).[3] The PDS is an advantageous tool in clinical research settings where pubertal status is required, but assessing Tanner staging (through either direct examinations or pictorial representations) is not feasible or too invasive/uncomfortable for the study participant.

The Petersen PDS includes scores for each of 5 items rating physical development (height; body hair; skin changes; voice changes, and facial hair for boys; breast development and menses for girls), an overall maturation measure, and a categorical maturation score (the Puberty Category Score) designed to be similar to Tanner staging categories.

An introductory statement to the adolescent is given prior to completion of the self-rating scale. Questions specific for male and female pubertal/physical development are included in the PDS. A version of the PDS adapted for our study is included in **Appendix 2** (**Appendix Table**).

Puberty Category Score

Puberty Category Scores are computed using the criteria of Crockett et al,[9] which have been summarized below. Although the PDS uses 5 items to rate physical development, 3 indices of pubertal change are thought to be most salient for each sex:

For girls, body hair growth, breast development, and menarche scores from the Petersen PDS are tallied, resulting in a Puberty Category Score. Because menarche is known to be a fairly late event in the pubertal process, girls reporting menstruation were considered late pubertal or postpubertal. Breast development and body hair growth were given less weight than menarche: prepubertal = 3, early puberty = 3 and no menarche; midpubertal = 4 and no menarche; late puberty = ≤7 and menarche; and postpubertal = 8 and menarche.

For the purpose of our study, we distinguished "late" pubertal development for girls as a Puberty Category Score of ≤7 and menarche or ≥8 and menarche.

For boys, body hair growth, voice change, and facial hair growth scores from the Petersen PDS are tallied, resulting in a Puberty Category Score. No discrete, defining pubertal event comparable with menarche in girls exists for boys. Instead, these 3 indices occur gradually over a period of time. Pubertal Category Scores for boys are classified as follows: prepubertal = 3; early pubertal = 4-5 (no 3-point responses); midpubertal = 6-8 (no 4-points); late pubertal = 9-11; and postpubertal = 12.

For the purpose of our study, we chose a Puberty Category Score of ≤8 as "early" and ≥9 as "late" for boys' pubertal development.

References

1. Petersen AC, Crockett L, Richards M, Boxer A. A self-report measure of pubertal status: reliability, validity, and initial norms. J Youth Adolesc 1988;17:117-33.
2. Carskadon MA, Acebo C. A self-administered rating scale for pubertal development. J Adolesc Health 1993;14:190-5.
3. Schmitz KE, Hovell MF, Nichols JF, Irvin VL, Keating K, Simon GM, et al. A validation study of early adolescents' pubertal self-assessments. J Early Adolesc 2004;24:357-84.
4. Coleman L, Coleman J. The measurement of puberty: a review. J Adolesc 2002;25:535-50.
5. Bond L, Clements J, Bertalli N, Evans-Whipp T, McMorris BJ, Patton G, et al. A comparison of self-reported puberty using the Pubertal Development Scale and the Sexual Maturation Scale in a school-based epidemiologic survey. J Adolesc 2006;29:709-20.
6. Brooks-Gunn J, Warren MP, Rosso J, Gargiulo J. Validity of self-report measures of girls' pubertal status. Child Dev 1987;58:829-41.
7. Duke PM, Litt IF, Gross RT. Adolescents' self-assessment of sexual maturation. Pediatrics 1860;66:918-20.
8. Schlossberger NM, Turner RA, Irwin CE. Validity of self-report of pubertal maturation in early adolescents. J Adolesc Health 1992;13:109-13.
9. Crockett LJ. Pubertal Developmental Scale: Pubertal categories. Unpublished manuscript 1988. (Copy available upon request from Prof. Anne Petersen, University of Minnesota Graduate School, 322 Johnston Hall, 101 Pleasant St SE, Minneapolis, MN 55455.)

Appendix 2

Pubertal Development Self-Rating Scale (Appendix Table)

Introduction: The next questions are about changes that may be happening to your body. These changes normally happen to youth and adolescents at different ages. In our study, we are attempting to determine whether there is a correlation between severity of concussive injury and the stage of pubertal development/physical maturity an athlete is currently in. Please try to answer these questions as honestly and accurately as you can. If you do not understand a question or do not know the answer, just mark "I do not know."

Appendix Table. Pubertal Developmental Self-Rating Scale

Question	Response options	Point value
1. Would you say that your growth in height:	has not yet begun to spurt	1
	has barely started	2
	is definitely underway	3
	seems completed	4
	I don't know	
2. And how about the growth of your body hair? ("Body hair" means hair any place other than your head, such as under your arms.) Would you say that your body hair growth:	has not yet begun to grow	1
	has barely started to grow	2
	is definitely underway	3
	seems completed	4
	I don't know	
3. Have you noticed any skin changes, especially pimples?	skin has not yet started changing	1
	skin has barely started changing	2
	skin changes are definitely underway	3
	skin changes seem complete	4
	I don't know	
FORM FOR BOYS:		
4. Have you noticed a deepening of your voice?	voice has not yet started changing	1
	voice has barely started changing	2
	voice changes are definitely underway	3
	voice changes seem complete	4
	I don't know	
5. Have you begun to grow hair on your face?	facial hair has not yet started growing	1
	facial hair has barely started growing	2
	facial hair growth has definitely started	3
	facial hair growth seems complete	4
	I don't know	
FORM FOR GIRLS:		
4. Have you noticed that your breasts have begun to grow?	have not yet started growing	1
	have barely started growing	2
	breast growth is definitely underway	3
	breast growth seems complete	4
	I don't know	
5a. Have you begun to menstruate (started to have your period)?	yes	4
	no	1
5b. If yes, how old were you when you started to menstruate?	age in years	____

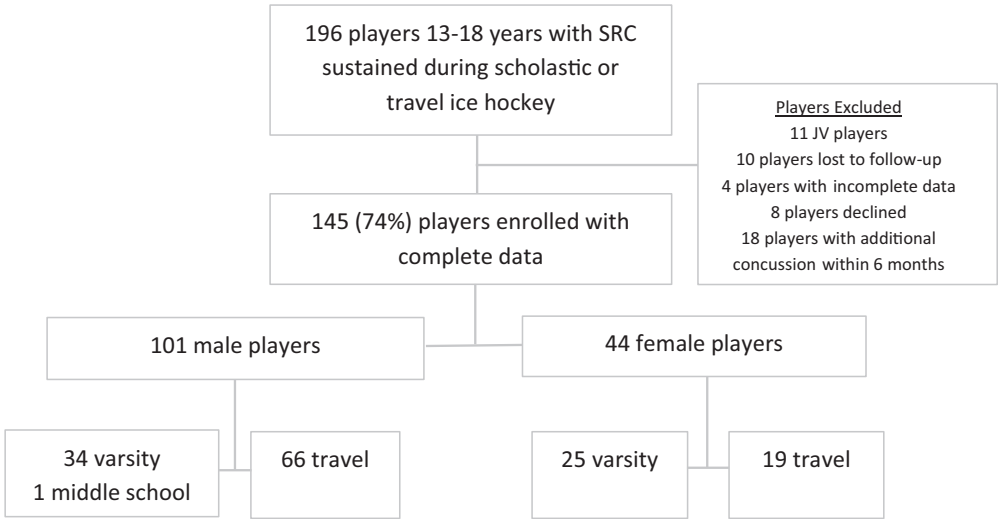

Figure 1. Selection process for study inclusion. *SRC*, sport-related concussion.