Risk of Injuries Associated With Sport Specialization and Intense Training Patterns in Young Athletes

A Longitudinal Clinical Case-Control Study

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Background: There are no clinical longitudinal studies exploring the associations between sport specialization and intense training patterns and injuries in young athletes.

Purpose: To prospectively determine the relationship between young athletes' degree of sport specialization and their risk of injuries and reinjuries.

Study Design: Case-control study; Level of evidence, 2.

Methods: Young athletes aged between 7 and 18 years presenting for sports-related injuries or sports physical examinations were recruited from either sports medicine clinics or pediatric/family medicine offices. Each participant completed a baseline survey at enrollment and an identical follow-up survey every 6 months for 3 years. Surveys assessed training patterns and injuries. Injury type (acute, overuse, or serious overuse) and clinical diagnosis were also recorded from electronic medical records.

Results: Of the 1208 participants who provided consent, 579 (48%) completed the baseline survey and first follow-up survey at 6 months (mean age, 14.1 ± 2.3 years; 53% female). Of this sample, 27% (158/579) of participants were uninjured, and 73% (421/579) were injured, with 29% (121/421) of injuries classified as reinjuries. Consistent with previous studies, over the 3-year study period, the degree of sport specialization had an effect such that more specialized athletes were significantly more likely to be injured ($P = .03$) or have an overuse injury ($P = .02$) compared with less specialized athletes after adjusting for potential confounders. Additionally, female athletes were more at risk for all injuries ($P = .01$) and overuse injuries ($P = .02$) after adjusting for covariates. Finally, young athletes who trained in weekly hours in excess of their age or who trained twice as many hours as their free play were significantly more likely to be injured on univariate analysis (both $P < .001$).

Conclusion: Our study confirms that over time, young athletes, and in particular young female athletes, were more likely to be injured and sustain an overuse injury if they had a higher degree of sport specialization. Similarly, those athletes whose training hours exceeded their age or whose sports hours exceeded their free play by a factor of greater than 2 were also more likely to develop injuries and overuse injuries.

Keywords: overuse injury; adolescent; specialization; growth rate; free play

Increasingly, children and adolescents are focusing and training year round in a single primary sport and at an early age.[16] These behaviors are in conflict with current recommendations for young athletes, which suggest participating in multiple sports and only specializing after middle adolescence or later.[2,4,8,11,13,19] These recommendations address numerous issues of concern among specialized athletes, including burnout or physical consequences such as injuries and overuse injuries.[3,7,8,21,22,27-29] Only recently have the independent effects of sport specialization and intense training patterns on injury risk in young athletes been documented.[1,10,13] We had previously demonstrated a cross-sectional association between single-sport specialization and a history of injuries in competitive Midwestern junior tennis players.[12] However, these data did not include other sports or specific clinical diagnoses. In a clinical case-control cohort study, we also demonstrated an independent risk of injuries, overuse injuries,

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and serious overuse injuries related to the degree of specialization when controlling for age and volume of training.[15] These findings have been reproduced in other nonclinical cross-sectional populations, particularly as they pertain to the overuse injury risk and degree of sport specialization.[1,10,20,25]

In an effort to use our data to inform clinical recommendations for young athletes, we investigated the total number of hours per week spent in organized sports training in relation to the athlete's age.[15] Based on our previously published data, athletes who trained for their sport more hours per week than their chronological age had a greater risk of serious overuse injuries than those training fewer hours than their age (odds ratio [OR], 2.07) on multivariate analysis.[15] Some experts now recommend limiting weekly training hours to fewer than the athlete's age to reduce the risk of injuries.[23] Additionally, a sports training ratio (weekly hours in organized sports/weekly hours in free play) was calculated based on reported weekly training hours to provide another clinical tool regarding the training risk and type of physical activity. We recommended that this ratio not exceed 2:1, as the OR of serious overuse injuries was 1.87 on multivariate analysis.[15]

While preliminary cross-sectional studies have suggested a relationship between the degree of sport specialization and the injury risk, these studies could not infer causality because of the lack of a longitudinal evaluation. Furthermore, there have been limited prospective data regarding the reinjury risk in a population of young athletes in varying degrees of sport specialization. In this prospective clinical cohort study of youth athletes, we evaluated (1) the longitudinal and independent effects of sport specialization on the risk of injuries and overuse injuries, (2) the effect of sports training patterns on the risk of reinjuries and overuse injuries, and (3) the longitudinal and independent effects of sex and age beginning sport specialization on the injury risk. Our hypotheses were that there would be a positive relationship between the risk of overuse injuries and the degree of sport specialization, that high-volume training patterns would result in a greater risk of overuse injuries, and that specialization would increase the risk of reinjuries, particularly with young female athletes who specialize early.

METHODS

Study Design and Participant Recruitment

This was a multicenter clinical prospective cohort study involving youth from Chicago, Illinois, USA. Children and adolescents with sports-related injuries were recruited from 1 of 2 university hospital–based primary care sports medicine clinics, and uninjured children were recruited from affiliated pediatric or family practice clinics during visits for preparticipation sports physical examinations or well-child care visits.

Children and adolescents who were aged 7 to 18 years and who participated in at least 1 organized sport during the year were invited to participate. Children and adolescents who did not participate in any organized sports were not invited to participate. Only data from those participants who completed the baseline survey and at least 1 follow-up survey were analyzed. Signed parental consent was obtained for each participant, and signed adolescent assent was obtained from participants aged $\geq$12 years. The institutional review boards of both respective institutions, Loyola University Medical Center and Ann & Robert H. Lurie Children's Hospital of Chicago, approved this study.

Participant Characteristics

Each participant's baseline height and weight were measured by a registered nursing staff member, medical assistant, athletic trainer, or research assistant at the time of enrollment. The body mass index (BMI) was calculated as kg/m^2. Follow-up anthropometric measurements were obtained from the participant's electronic medical record (EMR) when available or by self-report for participants who responded to follow-up surveys and did not have a recent visit noted on the EMR.

Surveys

All participants completed 2 surveys at enrollment: (1) current sport specialization (Appendix) and (2) self-assessment of pubertal maturation (Tanner stage). The Tanner stage as determined by self-assessment has been used previously; however, its reliability has been questioned.[5,26] The sport

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specialization survey included information regarding organized sports played throughout the year; hours per week in organized sports (training and competition), physical education (PE) class, and free play; sports enjoyment; and degree of sport specialization (see next section). Injured athletes also completed an injury survey to report injury mechanism, training before the injury, and whether the injury was new or recurrent. Additional injury information, such as physician diagnosis, acuity, and treatment, was obtained from the participant's EMR when available. Injuries acquired outside of organized sports were not recorded. Participants were asked to fill out a new sport specialization survey and injury survey (if a new injury occurred in the interim) every 6 months for 3 years; they were contacted every 6 months by email with weekly reminders and then also by telephone if not responding to email. There were no incentives provided for the completion of surveys.

Sport Specialization

While there has not been a consistent definition for sport specialization, we used a previously published definition: "year-round intensive training in a single sport at the exclusion of other sports."[13] Using this definition, we categorized the degree of sport specialization as low, moderate, or high based on the participant's answers to 3 survey questions: (1) Can you pick a main sport (ie, single-sport training)? (2) Did you quit other sports to focus on a main sport (ie, exclusion of other sports)? (3) Do you train more than 8 months in a year (ie, year-round training)? The number of "yes" answers to these 3 questions was used to assign a degree of specialization: 3 positive responses was categorized as highly specialized, 2 as moderately specialized, and $\leq$1 as low specialization. This approach to utilizing a degree of specialization was shown to be more reliable than using a binary definition in a population of high school athletes.[16] Because many organizations are interested in developing an age of specialization recommendation, we also considered an expanded definition of sport specialization by adding a fourth element: Did the athlete specialize (quit all other sports) under the age of 12 years? The scoring classification was the same as the original definition, except that if the answer was "yes" to all 4 questions, athletes were classified as extremely specialized.

Injury Characteristics

Injuries were classified using the clinical diagnoses obtained from the participant's EMR and injury mechanism (acute, overuse, or serious overuse) when available. Acute injuries were defined as those diagnoses that could be related to a single traumatic event, while overuse injuries were defined as those diagnoses that could be attributed to a gradual onset unrelated to a specific traumatic event. Overuse injuries were further categorized as "serious overuse" if the physician-recommended treatment typically required at least 1 month of rest from sports. Serious overuse injuries included spondylolysis, stress fractures to the spine or extremity, stress injuries involving the physes, elbow ligament overuse injuries, and osteochondritis dissecans.

A reinjury was defined using the participant's response to the following question: Is the injury you are being asked to talk about (describe) a repeat of an old injury, or is it a new injury? Any injury for which the participant stated that the injury produced similar symptoms/same pain as an old injury was classified as a "reinjury." Otherwise, if the participant described different symptoms/pain, it was classified as a "new injury."

Statistical Analysis

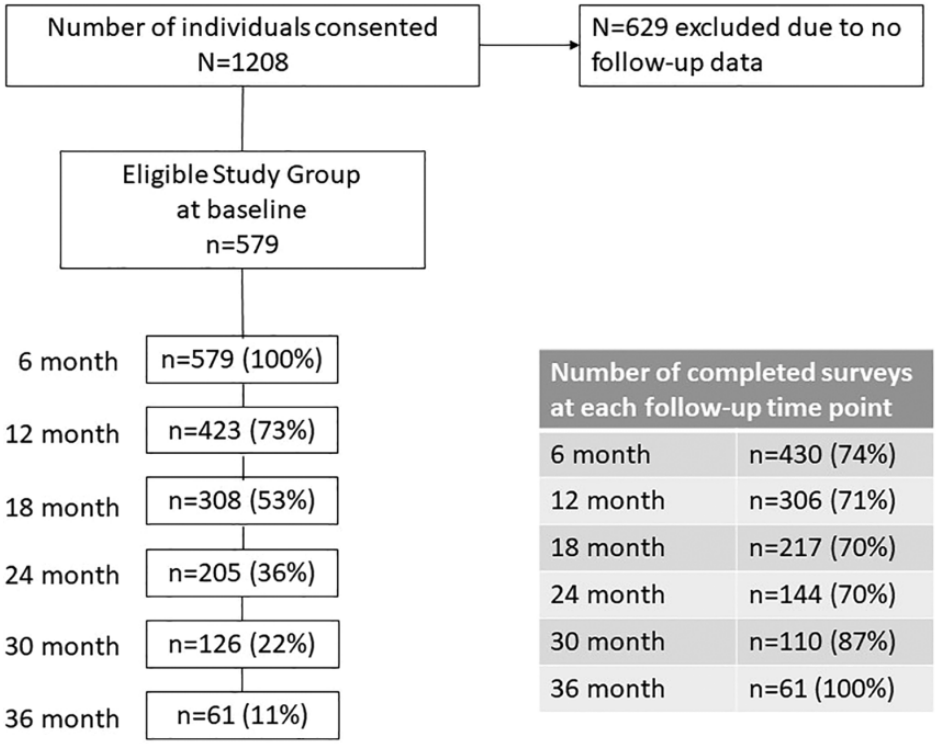
All analyses were conducted using SAS Version 9.4 (SAS Institute). Descriptive statistics including means and distributions were used to summarize the characteristics of injured versus uninjured participants at baseline. Independent variables evaluated included age, sex, hours per week of organized sports, hours per week of recreational free play, hours per week of PE class, and degree of sport specialization. The primary outcomes were total injuries, overuse injuries, serious overuse injuries, and reinjuries. For continuous measures (eg, age, weight, BMI, and weekly hours of organized sports, free play, PE class, and total physical activity), we report means and standard deviations or medians and interquartile ranges as appropriate. Frequencies and proportions are reported for categorical variables.

Univariable and multivariable generalized estimating equations with an exchangeable correlation structure were used to identify the association between sport specialization (time-varying covariate) and the injury risk over time, after adjusting for potential confounders such as sex, age, BMI, and variables identifying sports participation volume. Pairwise interactions with sport specialization were assessed. Because of the lack of significance in the univariable models and small injury counts, multivariable models were not constructed for serious overuse injury and reinjury outcomes. Final multivariable models for all-cause injuries and overuse injuries were determined via a combination of backward stepwise procedures and Akaike information criterion model selection using potentially significant variables identified on univariable analysis. Adjusted ORs and 95% CIs are reported. Sensitivity analyses were additionally conducted using all available data through 1 and 2 years, respectively, to assess the potential impact of dropouts on the 3-year association between specialization and injuries.

RESULTS

Participant Characteristics

Of 1208 participants who enrolled and provided consent at baseline, 629 were excluded because of no follow-up information, resulting in a final study sample of 579 (48%) participants who completed at least the baseline survey and first follow-up survey at 6 months. By the 18-month follow-up survey, 308 of the 579 (53%) participants remained in the study. At the 3-year mark, only 11%



Number of completed surveys at each follow-up time point	
6 month	n=430 (74%)
12 month	n=306 (71%)
18 month	n=217 (70%)
24 month	n=144 (70%)
30 month	n=110 (87%)
36 month	n=61 (100%)

Figure 1. Survey responses.

(61/579) completed the sports participation and injury survey (Figure 1).

At baseline, 421 (73%) participants were injured (Table 1). The mean age at baseline was 14.05 ± 2.26 years, with injured participants being slightly older (14.41 ± 2.08 years) than uninjured participants (13.03 ± 2.46 years) ($P <$ .001). Additionally, participants injured at baseline participated in more organized sports hours per week ($P = .007$), had a higher median ratio of organized sports to free play ($P = .002$), were more likely to exceed 8 months per year of sports training ($P = .003$), and were more likely to be highly specialized (31% injured vs 18% uninjured) ($P < .001$). Because age, sports hours, and months of training were significant on univariable analysis, they were all considered in the multivariable analysis.

Injury Characteristics Over Time

Table 2 provides injury characteristics over the study period. At baseline, only 29% (121/421) of injuries were classified as reinjuries. However, a majority of injuries during the follow-up period were classified as reinjuries throughout the first 24 months (~70%-80% through the first 24 months). Similarly, only 33% (157/475) of injuries reported during the follow-up period were new injuries. Of all injuries reported during the study (at baseline and during follow-up), 41% (368/896) were classified as overuse injuries (34%-53% at each time point). Serious overuse injuries accounted for 8% of all injuries and 19% of all overuse injuries. The most commonly injured body parts reported in the data set were the knee (n = 199 [22%]), ankle and foot (n = 161 [18%]), and low back (n = 128 [14%]).

Sport Specialization Patterns Over Time

It was expected that sport specialization would increase over time; however, no trend in sport specialization was detected using the original definition of specialization ($P = .11$) (Table 3). This may in part be because of large dropout rates after 18 months. High sport specialization reached its peak with 40% of participants during the 18-month follow-up survey, while low specialization was at its lowest with 37% at the same time point. Using the expanded definition of sport specialization (age <12 years), a test for trend identified an increase in the proportion of extreme specializers over the 3-year period and a decrease in low specializers ($P < .001$); however, the rate of specialization stayed relatively consistent among the moderate and high specializers.

Longitudinal Analysis of All-Cause Injuries and Reinjuries

On univariable analysis, female sex (OR, 1.28 [95% CI, 1.01-1.62]; $P = .04$), increasing chronological age (OR, 1.11 [95% CI, 1.05-1.17]; $P < .001$), higher BMI (OR, 1.04 [95% CI, 1.12-1.27]; $P = .05$), and increased weekly hours of physical activity (OR, 1.19 per 5 h/wk [95% CI, 1.02-1.05]; $P < .001$) and of organized sports (OR, 1.39 per 5 h/wk [95% CI, 1.27-1.52]; $P < .001$) all contributed to greater odds of

TABLE 1
Participant Characteristics at Baseline[a]

	Uninjured (n = 158)	Injured (n = 421)	Total (N = 579)	*P* Value
Male sex, n (%)	79 (50)	190 (45)	269 (47)	.30
Age, y	13.03 ± 2.46	14.41 ± 2.08	14.05 ± 2.26	<.001
Age at specialization (n = 237), y	11.17 ± 2.72	11.72 ± 2.53	11.61 ± 2.57	.18
Specialization at age <12 y (n = 237), n (%)	23 (48)	101 (53)	124 (52)	.49
BMI, kg/m^2				
Female	20.55 ± 3.45	21.87 ± 3.47	21.63 ± 3.49	.06
Male	21.80 ± 4.95	22.94 ± 5.17	22.59 ± 5.12	.16
Tanner stage, median (IQR)				
Male pubic (n = 196)	2 (1-4)	3 (2-4)	3 (2-4)	<.001
Female breast (n = 217)	3 (2-4)	4 (4-4.5)	4 (3-4)	<.001
Female pubic (n = 217)	3 (2-3)	3 (3-4)	4 (3-4)	<.001
Total physical activity, h/wk	17.70 ± 9.32	19.23 ± 8.59	18.81 ± 8.82	.06
PE class, h/wk	3.06 ± 1.77	3.12 ± 2.02	3.10 ± 1.95	.76
Free play, h/wk	5.30 ± 4.69	5.23 ± 5.31	5.25 ± 5.14	.89
Organized sports, h/wk	9.53 ± 6.30	11.18 ± 5.84	10.73 ± 6.14	.007
Ratio of organized sports to free play >2:1 (n = 558), n (%)	73 (46)	228 (56)	301 (54)	.06
Ratio of organized sports to free play, median (IQR)	2.00 (0.83-4.00)	3.00 (1.25-6.25)	2.50 (1.00-6.00)	.002
Training for main sport, median (IQR), mo/y	10 (6-12)	10 (6-12)	10 (6-12)	.14
Degree of sport specialization, n (%)				<.001
Low	89 (56)	164 (39)	253 (44)	
Moderate	40 (25)	125 (30)	165 (29)	
High	29 (18)	132 (31)	161 (28)	
Expanded degree of sport specialization, n (%)				.02
Low	66 (42)	133 (32)	199 (34)	
Moderate	46 (29)	123 (29)	169 (29)	
High	30 (19)	129 (31)	159 (27)	
Extreme	16 (10)	36 (9)	52 (9)	
Weekly sports hours exceeding age (n = 472), n (%)	23 (19)	84 (24)	107 (23)	.24
Exceeding 8 mo/y of sports training, n (%)	63 (40)	226 (54)	289 (50)	.003

[a]Data are shown as mean ± SD unless otherwise indicated. *P* values represent comparisons between the uninjured vs injured groups. Percentages may be taken from different subpopulation calculations based on overall cohort for each variable. BMI, body mass index; IQR, interquartile range; PE, physical education.

TABLE 2
Injury Characteristics Over Time[a]

	Baseline	6 mo	12 mo	18 mo	24 mo	30 mo	36 mo	Total
Injury status								
New injury	300 (71)	45 (26)	35 (31)	17 (22)	15 (25)	32 (76)	13 (87)	457 (51)
Reinjury	121 (29)	125 (74)	77 (69)	60 (78)	44 (75)	10 (24)	2 (13)	439 (49)
Injury type								
Overuse	176 (42)	58 (34)	44 (39)	31 (40)	31 (53)	22 (52)	6 (40)	368 (41)
nontraumatic								
Serious overuse	39 (22)	11 (19)	5 (11)	5 (16)	8 (26)	2 (9)	0 (0)	70 (19)
Normal overuse	137 (78)	47 (81)	39 (89)	26 (84)	23 (74)	20 (91)	6 (100)	298 (81)
Traumatic/acute	245 (58)	112 (66)	68 (61)	46 (60)	28 (48)	20 (48)	9 (60)	528 (59)
Total[b]	421 (73)	170 (29)	112 (26)	77 (25)	59 (29)	42 (33)	15 (25)	896 (100)[c]

[a]Data are shown as n (%).
[b]Percentages represent those of athletes enrolled at each time point who reported an injury.
[c]A total of 896 injuries were reported in 421 athletes over the entire study period.

injuries (Table 4). Athletes who exceeded a ratio of 2:1 for weekly hours in organized sports to free play, those who spent more weekly hours in organized sports than their age, and those who spent more than 8 months per year in organized sports training had greater odds of all-cause injuries and overuse injuries during the study period (baseline and follow-up) compared with those who did not meet the criteria. Highly specialized athletes throughout the study period had 1.72 times greater odds of an injury than low specialized athletes (95% CI, 1.35-2.20) and 1.52 times

TABLE 3
Degree of Sport Specialization Over Time[a]

	Baseline	6 mo	12 mo	18 mo	24 mo	30 mo	36 mo	*P* Value[b]
Original definition								.11
Low	253 (44)	221 (50)	124 (41)	81 (37)	63 (44)	51 (46)	36 (59)	
Moderate	165 (29)	98 (23)	73 (24)	50 (23)	31 (22)	20 (18)	11 (18)	
High	161 (28)	111 (26)	109 (36)	86 (40)	50 (35)	39 (35)	14 (23)	
Expanded definition								<.001
Low	199 (34)	158 (37)	91 (30)	50 (23)	31 (22)	23 (21)	22 (36)	
Moderate	169 (29)	85 (20)	54 (18)	51 (24)	33 (23)	28 (25)	14 (23)	
High	159 (27)	107 (25)	75 (25)	60 (28)	31 (22)	20 (18)	11 (18)	
Extreme	52 (9)	80 (19)	86 (28)	56 (26)	49 (34)	39 (35)	14 (23)	

[a]Data are shown as n (%).
[b]A Somers' D test over time was conducted.

TABLE 4
Univariable ORs for Injury Status[a]

	All Injuries		Overuse		Serious Overuse		Reinjuries	
	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
Female sex	1.28 (1.01-1.62)	.04	1.50 (1.14-1.99)	.004	0.69 (0.40-1.19)	.18	1.05 (0.79-1.38)	.75
Age	1.11 (1.05-1.17)	<.001	1.01 (0.95-1.07)	.77	0.94 (0.81-1.08)	.38	1.08 (1.01-1.15)	.02
Age at specialization	0.98 (0.91-1.05)	.54	0.95 (0.88-1.02)	.16	1.11 (0.92-1.33)	.28	1.01 (0.94-1.10)	.74
Specialization at age <12 y	1.05 (0.75-1.48)	.76	1.35 (0.93-1.96)	.12	0.55 (0.23-1.30)	.17	0.85 (0.57-1.26)	.42
BMI	1.04 (1.12-1.27)	.05	0.98 (0.94-1.01)	.21	1.00 (0.92-1.10)	.95	0.99 (0.96-1.03)	.78
Total physical activity (5 h/wk)	1.19 (1.02-1.05)	<.001	1.12 (1.05-1.20)	.001	1.06 (0.92-1.21)	.43	0.94 (0.87-1.01)	.10
Weekly sports hours (5 h/wk)	1.39 (1.27-1.52)	<.001	1.24 (1.11-1.39)	<.001	1.16 (0.97-1.39)	.11	0.96 (0.86-1.07)	.44
Weekly hours in ratio of organized sports to free play >2:1	1.55 (1.28-1.89)	<.001	1.46 (1.14-1.89)	.003	1.13 (0.67-1.90)	.65	1.03 (0.79-1.34)	.82
Weekly organized sports hours exceeding age	1.71 (1.30-2.27)	<.001	1.68 (1.25-2.25)	<.001	1.25 (0.65-2.40)	.88	1.28 (0.94-1.74)	.12
Exceeding 8 mo/y of sports training	1.43 (1.17-1.76)	<.001	1.58 (1.23-2.04)	<.001	1.36 (0.79-2.34)	.26	0.88 (0.67-1.16)	.37
Degree of sport specialization		<.001		<.001		.20		.35
Moderate	1.52 (1.18-1.96)	.001	1.68 (1.24-2.27)	<.001	1.71 (0.92-3.17)	.09	0.84 (0.60-1.19)	.34
High	1.72 (1.35-2.20)	<.001	1.78 (1.30-2.42)	<.001	0.96 (0.49-1.90)	.91	1.09 (0.79-1.49)	.61
Expanded degree of sport specialization		<.001		.001		.20		.48
Moderate	1.39 (1.08-1.78)	.01	1.20 (0.87-1.66)	.26	1.56 (0.78-3.11)	.21	0.75 (0.52-1.09)	.14
High	1.69 (1.31-2.18)	<.001	1.97 (1.43-2.72)	<.001	1.76 (0.89-3.50)	.11	0.97 (0.69-1.35)	.85
Extreme	1.29 (0.95-1.74)	.10	1.41 (0.95-2.07)	.09	0.83 (0.30-2.30)	.72	0.88 (0.58-1.35)	.56

[a]Reference levels for categorical variables: specialization at age <12 y (no), weekly hours in ratio of organized sports to free play >2:1 (no), weekly organized sports hours exceeding age (no), exceeding 8 mo/y of sports training (no), Degree of sport specialization (low), expanded degree of sport specialization (low). BMI, body mass index; OR, odds ratio.

greater odds of an injury than moderately specialized athletes (95% CI, 1.18-1.96). Although not statistically significant, there was a trend toward extremely specialized athletes (via the expanded definition of specialization) to have greater odds of injuries compared with low specialized athletes (OR, 1.29 [95% CI, 0.95-1.74]; $P = .10$). No association was detected between age at specialization and the injury risk ($P = .54$). Moreover, no variables significantly increased the odds of a reinjury on univariable analysis.

Multivariable analysis showed that after adjusting for sex, age, time from baseline, BMI, and weekly hours in organized sports, highly specialized athletes were 1.41 (95% CI, 1.06-1.87) times more likely to experience an injury than low specialized athletes ($P = .02$) (Table 5). Similarly, moderately specialized athletes had an increased risk of injuries compared with low specialized athletes (OR, 1.38 [95% CI, 1.04-1.84]). After controlling for sex, age, time, BMI, and degree of specialization, the odds of an injury increased by 31% (OR, 1.31 [95% CI, 1.19-1.44]) for every 5 hours per week of organized sports activity ($P < .001$). Similar patterns were found using the expanded sport specialization definition, and results are reported in Appendix Table A1.

Longitudinal Analysis of Overuse and Serious Overuse Injuries

Female sex (OR, 1.50 [95% CI, 1.14-1.99]; $P = .004$), increased weekly hours of physical activity (OR, 1.12 per 5 h/wk [95% CI, 1.05-1.20]; $P = .001$), and increased weekly

TABLE 5
Multivariable ORs for Injury Status[a]

	OR (95% CI)	*P* Value
All injuries		
Female sex	1.43 (1.09-1.83)	.01
Age	1.07 (1.01-1.13)	.02
Time	0.69 (0.64-0.74)	<.001
BMI	1.02 (0.99-1.06)	.14
Weekly sports hours (5 h/wk)	1.31 (1.19-1.44)	<.001
Degree of sport specialization		.03
Moderate	1.38 (1.04-1.84)	.02
High	1.41 (1.06-1.87)	.02
Overuse injuries		
Female sex	1.43 (1.05-1.96)	.02
Time	0.84 (0.77-0.92)	<.001
BMI	0.98 (0.95-1.02)	.32
Total physical activity (5 h/wk)	0.87 (0.75-1.01)	.07
Weekly sports hours (5 h/wk)	1.31 (1.07-1.59)	.007
Weekly organized sports hours exceeding age	1.18 (0.77-1.80)	.44
Degree of sport specialization		.02
Moderate	1.58 (1.13-2.20)	.007
High	1.46 (1.04-2.04)	.03

[a]Reference levels for categorical variables: female sex (male), degree of sport specialization (low), weekly organized sports hours exceeding age (no). BMI, body mass index; OR, odds ratio.

hours of organized sports (OR, 1.24 per 5 h/wk [95% CI, 1.11-1.39]; $P < .001$) were associated with overuse injuries on univariable analysis (Table 4). The lack of adherence to published recommendations was associated with increased odds of overuse injuries during the study period (>2:1 sports/free play ratio: $P = .003$; weekly sports hours greater than age: $P < .001$; >8 mo/y of sports training: $P < .001$). Higher levels of sport specialization were also associated with an increased risk of overuse injuries ($P < .001$). Age at specialization ($P = .16$), chronological age ($P = .77$), and BMI ($P = .21$) were not univariably associated with the risk of overuse injuries. No univariable associations were detected with serious overuse injuries during the study period.

The final multivariable model for overuse injuries consisted of the following variables: sex, time, BMI, total weekly hours of physical activity, weekly sports hours, exceeding the weekly hours of organized sports by the age recommendation, and degree of sport specialization (Table 5). After controlling for all variables in the model, athletes categorized as highly specialized had 1.46 (95% CI, 1.04-2.04) times greater odds of an overuse injury than low specialized athletes ($P = .03$). Athletes categorized as moderately specialized had 1.58 (95% CI, 1.13-2.20) times greater odds of an overuse injury than low specialized athletes ($P = .007$). Additionally, female athletes had 1.43 (95% CI, 1.05-1.96) times greater odds of an overuse injury compared with male athletes ($P = .02$). Similar patterns were found using the expanded sport specialization definition, and results are reported in Appendix Table A1. The results of sensitivity analyses of 1- and 2-year follow-up were similar to the associations reported for 3-year follow-up (Appendix Tables A2 and A3).

DISCUSSION

Prospective studies have previously been performed to evaluate the association between sport specialization and injury risk.[18,20] However, we believe that this is the first clinical study to report the relationship between sport specialization and injury risk in a longitudinal sample of young athletes. Furthermore, we believe that it is the first study to report the reinjury risk in a clinical population of young athletes. While our data demonstrate an association between an increased injury risk (both all-cause and overuse) and higher levels of specialization, we could not confirm an association between reinjury risk and degree of sport specialization in our study.

Sport Specialization and Injury Risk

The longitudinal findings support our previous cross-sectional study conclusions that indicated an independent positive association between increased sport specialization and the risk of injuries.[15] While this association between the injury risk and sport specialization has been confirmed in other cross-sectional populations,[1,10,20,24,25] there is no known published longitudinal study confirming that increased sport specialization may be causal for injuries in a clinical population of young athletes. Indeed, our data confirm that there is an increase in the overuse injury risk with higher degrees of sport specialization longitudinally, although this association was not seen for acute injuries. Previously, McGuine et al[20] explored the injury risk related to the degree of specialization in a 2-year longitudinal study of high school athletes (mean age, 16.1 years). Their study used data reported from high school athletic trainers in a variety of sports and confirmed some of the relationships between degree of sport specialization and overuse injury risk seen in our original baseline data.[20] However, sport specialization selection may often occur before high school, and in the study by McGuine et al, the rates of sport specialization were not evaluated over time. The mean age of participants in the current study was 14.1 years, and we included athletes from a variety of settings as well as club sports and also included a clinical diagnosis by a physician.

In the current study, sport specialization continued to be a risk factor, independent of age and training volume, which supports the conclusion that sport specialization alone may increase the risk of injuries even with similar training volumes. Although data are limited, a number of position and policy statements from various organizations, such as the American Academy of Pediatrics, AOSSM, and American Medical Society for Sports Medicine, have supported the recommendation to delay or limit sport specialization in young athletes.[4,9,11,19] The consensus from most sports medicine organizations is to recommend against early sport specialization because of the risk of injuries, burnout, and long-term attrition and health consequences.[3,8,13,21,27-29]

Therefore, we recommend that young athletes proceed with caution when choosing to specialize and that they understand the potential increased risk of injuries and particularly overuse injuries.

Reinjuries

We did not find an association between sport specialization and reinjury risk ($P = .35$) (Table 4). However, we found that there were 896 injuries reported over the study period, with 49% of these being reinjuries (see Table 2). Overuse injuries constituted 41% of all injuries. It has previously been suggested that approximately 50% of young athletes' injuries are overuse injuries.[9] This distribution of total injuries, reinjuries, and overuse injuries is generally consistent but is potentially associated with selection bias, as this was a clinical population primarily from sports medicine practices.

Training

Training more hours per week than one's age and exceeding a 2:1 sports training ratio (organized to free play) have previously been associated with an increased risk of overuse injuries. In this longitudinal follow-up study, there was a higher proportion of injured athletes who trained more hours per week than their age and who exceeded the 2:1 sports training ratio. Specifically, it appears that exceeding these volume recommendations may continue to be a risk for the development of overuse injuries. This suggests that a framework of including age-appropriate volume-based recommendations for young athletes may help to reduce the risk of overuse injuries. One strategy to address this may be increasing the amount of self-directed free play. Kliethermes et al[17] demonstrated in a randomized controlled trial that young athletes who received serial evidence-based counseling (that included these recommendations) demonstrated fewer injuries over the course of the study period of 9 months compared with those who did not receive such counseling. While this finding was not statistically significant, it may suggest that adherence to age-appropriate volume recommendations may modify the risk of injuries.

Sex

The sex differences in young athletes for overuse injuries have been previously reported.[23] In the current population of young athletes, 41% were identified as having overuse injuries, with female athletes more likely to report any injury and an overuse injury. Jayanthi and Dugas[14] previously reported that the likely main influence on overuse injury risk in specialized athletes was female sex. This is a novel consideration, as young female athletes have previously been demonstrated to have neuromuscular and genetic influences that significantly increase the risk of anterior cruciate ligament injuries. While biomechanical factors have not been adequately investigated in the setting of sport specialization, one potential explanation is that young female athletes have a greater risk of overuse injuries based on sports types (individual, technical) that involve higher rates of specialization, a small subset of repetitive movement patterns (eg, serving in volleyball), and early intense year-round training. A recent biomechanical analysis of young female athletes does suggest that there may be higher knee abduction forces in specialized athletes.[6] Further study is needed to elucidate other modifiable risk factors for overuse injuries in the young female athlete.

Age at Specialization

Our longitudinal univariable results also did not detect an association between age at specialization or specialization before the age of 12 years and the all-injury risk. However, statistically, there was a trend toward a protective effect on overuse injury risk when specializing at later ages. There were also no differences in injury risk based on age at specialization in a previous clinical study of young athletes (>12 vs 11.8 years).[15] There are still no studies to date that have clearly demonstrated injury risk as related to a specific age of sport specialization. This may be because the studies are often cross-sectional, with a variety of sports that might diminish the potential effects of a specific sport. Additionally, the Tanner developmental stage may potentially be a better indicator for injury risk, particularly during ages when there is rapid growth. In this study, young athletes with later median Tanner stages for male pubic (stage 3), female pubic (stage 3), and breast (stage 4) were more likely to be injured in the baseline sample ($P < .001$ for all) (see Table 1); however, this did not persist in longitudinal analysis. Future studies may consider sport-specific populations evaluated longitudinally during adolescence and rapid growth periods to discern sport-specific age of specialization or development recommendations.

Sport Specialization Over Time

No prior study has evaluated the effects of sport specialization over time. We found that there were no significant differences for the distribution of sport specialization from baseline to 36 months ($P = .11$). However, the overuse injury risk did increase with time, and the degree of sport specialization was related to injury risk over time. This may suggest that there is a relationship between the degree of specialization and the longitudinal injury risk. Because this relationship persisted even when adjusting for exposure, we feel that there may be an independent contribution of injury and overuse injury risk related to the degree of sport specialization over time. Naturally, as these participants age, they may be more likely to be more specialized; however, this may be balanced by some of the previously highly specialized young athletes also becoming more diversified over time.

Limitations

Because this study included a sample of clinical patients from 2 large Midwestern institutions, one should not overgeneralize the findings to a broad population or school-based environment. There were no financial or other incentives to remain in the study, so there was significant attrition in response rates after 2 years, and as a result, the

longitudinal follow-up beyond 2 years was low, making it harder to make firm conclusions. Yet, sensitivity analyses of 1- and 2-year follow-up data (see Appendix Tables A2 and A3) suggest similar associations as those presented for 3-year follow-up. In addition, a majority of injuries during the follow-up period were classified as reinjuries throughout the first 24 months, which may have influenced injury type findings. The changes in sport specialization over time were captured only as a group variable and therefore do not necessarily reflect a participant's change in sport specialization status. Additionally, we did not account for sports or sports type in the relationship of injuries to sport specialization. We recommend for this to be evaluated in sport-specific studies. Selection bias is expected, particularly in the follow-up sample, as sports medicine physicians included in the study primarily saw injured young athletes rather than healthy athletes. Those participants who were diagnosed with a sports injury in the clinic may have been more likely to follow up because they had an injury to report during the follow-up period.

CONCLUSION

This is the first study to report an association between the degree of sport specialization and the risk of injury in a clinical cohort of young athletes followed for 3 years. Highly specialized athletes, female athletes, and those who trained more hours per week than their age were more likely to develop injuries and overuse injuries, even when accounting for age and hours of week of training. Reinjury rates were approximately 50% over the study period, but there was no association between reinjury rate and volume of specialized training.

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APPENDIX

Sport Specialization Survey

Please check **one box** for **each question**, and answer all the questions to the best of your ability with the help of a parent.

1. **What sports** do you compete (play games/matches) in during the course of the year? (Please list all)
   1. _____ 2. _____ 3. _____
   4. _____ 5. _____
2. **During the last 6 months,** in a typical week, how many **hours per week** did you spend:
   a. In gym class?
      ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
   b. Playing sports just for fun? (This includes, for example, playing outside after school or at recess.)
      ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11 ☐ 12 ☐ 13 ☐ 14 ☐ 15 ☐ 16 ☐ 17 ☐ 18 ☐ 19 ☐ 20
      (if more than 20, please write the number of hours) _____
   c. Playing competitive sports (at practice for a sport that you compete in?)
      ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11 ☐ 12 ☐ 13 ☐ 14 ☐ 15 ☐ 16 ☐ 17 ☐ 18 ☐ 19 ☐ 20
      (if more than 20, please write the number of hours) _____
3. **How old were you** when you started to participate in **COMPETITIVE** sports (play in matches, games, tournaments, meets, etc.?)
   ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11 ☐ 12 ☐ 13 ☐ 14 ☐ 15 ☐ 16 ☐ 17 ☐ 18
4. Do you have at least one day a week every week that you don't play any sports?
   ☐ Yes ☐ No
5. **Have you had an injury** in the last 6 months related to sports that has prevented you from playing sports?
   ☐ Yes ☐ No
6. **Would you agree or disagree with the following statement: *"I spend more than 75% (or ¾) of my training in only one organized (team) sport"*?**
   ☐ Agree ☐ Disagree
7. **Do you agree with the following statements:**
   a. At practice, I think learning something new or improving my skill is more important than having fun with my friends.
      ☐ Agree ☐ Disagree
   b. I often miss spending time with my friends that don't play sports because I have practice or competition (games, matches, tournaments, etc.) for my sport.
      ☐ Agree ☐ Disagree
8. **Have you quit other sports to focus on one main sport?**
   ☐ Yes ☐ No
   a. **If yes**, how old were you when you quit other sports?
      ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11 ☐ 12 ☐ 13 ☐ 14 ☐ 15 ☐ 16 ☐ 17 ☐ 18
9. **Is one of your sports more important** to you than any other sport?
   ☐ Yes ☐ No
   a. If yes, please name the sport _____

PLEASE ONLY ANSWER QUESTIONS 10 & 11 IF YOU HAVE **ONE SPORT** THAT IS **MORE IMPORTANT** THAN ANY OTHER.

10. **Do you REGULARLY travel** to other states **to compete** in your sport?
    ☐ Yes ☐ No
11. **How many months** per year do you:
    a. **Train** (practice) for ONE MAIN SPORT?
       ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11 ☐ 12
    b. **Compete** (play in games, tournaments, matches, meets, etc) in ONE MAIN SPORT?
       ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11 ☐ 12
12. Please mark a **vertical line** (up and down) on the scale that marks how much you enjoy playing sports.

DEVELOPMENT (PRIVATE) QUESTIONS

13. **(For Boys and Girls):** Do you have any growth of pubic hair (hair in the "private areas")?
    ☐ Yes ☐ No
14. **(GIRLS ONLY)** Have you had a menstrual period or menstrual cycle yet?
    ☐ Yes ☐ No
15. 15. **(BOYS ONLY)** Do you have facial hair or need to shave yet?
    ☐ Yes ☐ No

APPROXIMATE DATE OF INJURY:___/____/___

Diagnosis (if unknown, please describe your injury): _____

1. Is the injury you're being asked to talk about (describe) a repeat of an old injury or is it a new injury?
   ☐ New injury ☐ Same pain/similar symptoms
2. Was this injury a traumatic (acute) injury? (Was there a single injury or movement that caused your pain/injury?)
   ☐ Yes ☐ No
3. Can you describe the location of your injury?
   ☐ 1 Head/neck ☐ 2 Shoulder ☐ 3 Elbow ☐ 4 Hand/wrist ☐ 5 Hip/pelvis/thigh
   ☐ 6 Low back ☐ 7 Knee ☐ 8 Leg ☐ 9 Foot/ankle ☐ 10 Other_____
4. Please mark the amount to which this injury limits (or limited) your sports participation. (Please choose only one answer.)
   ☐ 5 – participation remained normal
   ☐ 4 – participation remained normal, but pain occurred follow activity/sport
   ☐ 3 – pain during activity that affected performance, but continued activity
   ☐ 2 – pain during activity caused you to stop activity/sport
   ☐ 1 – pain prevented any participation in sports activity
5. Has (did) the injury cause you to miss any practice?
   ☐ Yes ☐ No
6. Has (did) the injury cause you to miss any competition (games, tournaments, matches, etc.)?
   ☐ Yes ☐ No
7. To date, how many days of practice has your injury caused you to miss?
   ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11 ☐ 12 ☐ 13 ☐ 14 ☐ 15 ☐ 16 ☐ 17 ☐ 18 ☐ 19 ☐ 20
   (if more than 20, please write the number of days) _____
8. Do you feel you had a "growth spurt" in the last 6 months prior to injury?
   ☐ Yes ☐ No If Yes, approximately how much did you grow in the 6 months prior to injury? _____inches
9. In the **last 4 weeks prior to injury**, did you:
   a. Increase the amount of hours per week you were training?
   ☐ Yes ☐ No
   b. Learn a new technique or skill?
   ☐ Yes ☐ No
   c. Use new or different equipment?
   ☐ Yes ☐ No
10. Have you quit any sport in the last 6 months?
    ☐ Yes ☐ No
    (If your **answer** to **#10** is **"no"**, **<u>then you are done</u>**. If, "**yes**," please **<u>continue</u>**)
11. If you quit a sport in the last 6 months,
    a. Was this your primary or most important sport?
       ☐ Yes ☐ No
    b. Was your decision to quit related to an injury?
       ☐ Yes ☐ No
    c. Did you quit so that you could focus on another sport?
       ☐ Yes ☐ No

TABLE A1
Multivariable ORs for Injury Status Using Expanded Definition of Sport Specialization[a]

	OR (95% CI)	*P* Value
All injuries		
Female sex	1.56 (1.16-2.11)	.003
Age	1.11 (1.04-1.19)	.003
Time	0.42 (0.35-0.50)	<.001
BMI	1.02 (0.99-1.06)	.26
Weekly sports hours (5 h/wk)	1.34 (1.18-1.52)	<.001
Degree of sport specialization		.37
Moderate	1.16 (0.81-1.66)	.41
High	1.35 (0.96-1.90)	.08
Extreme	1.38 (0.62-3.08)	.43
Overuse injuries		
Female sex	1.77 (1.16-2.70)	.007
Time	0.55 (0.45-0.68)	<.001
BMI	0.98 (0.95-1.02)	.34
Total physical activity (5 h/wk)	0.85 (0.72-1.00)	.05
Weekly sports hours (5 h/wk)	1.42 (1.12-1.79)	.004
Weekly organized sports hours exceeding age	1.19 (0.72-1.97)	.50
Degree of sport specialization		.03
Moderate	1.07 (0.71-1.63)	.74
High	1.37 (0.92-2.03)	.12
Extreme	1.40 (0.56-3.58)	.47

[a]Reference levels for categorical variables: female sex (male), degree of sport specialization (low), weekly organized sports hours exceeding age (no). BMI, body mass index; OR, odds ratio.

TABLE A2
Multivariable ORs for Injury Status Using Data Collected From First 2 Years[a]

	OR (95% CI)	*P* Value
All injuries		
Female sex	1.42 (1.08-1.87)	.01
Age	1.07 (1.01-1.14)	.03
Time	0.62 (0.57-0.68)	<.001
BMI	1.02 (0.99-1.06)	.14
Weekly sports hours (5 h/wk)	1.33 (1.20-1.48)	<.001
Degree of sport specialization		.02
Moderate	1.38 (1.01-1.89)	.04
High	1.46 (1.09-1.95)	.01
Overuse injuries		
Female sex	1.39 (1.00-1.93)	.04
Time	0.79 (0.70-0.89)	<.001
BMI	0.99 (0.95-1.02)	.36
Total physical activity (5 h/wk)	0.87 (0.75-1.01)	.07
Weekly sports hours (5 h/wk)	1.30 (1.06-1.60)	.01
Weekly organized sports hours exceeding age	1.17 (0.75-1.83)	.49
Degree of sport specialization		.03
Moderate	1.53 (1.07-2.17)	.02
High	1.48 (1.04-2.10)	.03

[a]Reference levels for categorical variables: female sex (male), degree of sport specialization (low), weekly organized sports hours exceeding age (no). BMI, body mass index; OR, odds ratio.

TABLE A3
Multivariable ORs for Injury Status Using Data Collected From First Year[a]

	OR (95% CI)	*P* Value
All injuries		
Female sex	1.55 (1.15-2.08)	.004
Age	1.09 (1.03-1.17)	.008
Time	0.42 (0.35-0.50)	<.001
BMI	1.02 (0.99-1.06)	.24
Weekly sports hours (5 h/wk)	1.32 (1.16-1.50)	<.001
Degree of sport specialization		.03
Moderate	1.43 (1.00-2.06)	.05
High	1.52 (1.08-2.15)	.02
Overuse injuries		
Female sex	1.39 (1.00-1.93)	.04
Time	0.55 (0.45-0.68)	<.001
BMI	0.98 (0.95-1.02)	.29
Total physical activity (5 h/wk)	0.84 (0.71-1.00)	.05
Weekly sports hours (5 h/wk)	1.40 (1.10-1.76)	.01
Weekly organized sports hours exceeding age	1.23 (0.74-2.04)	.42
Degree of sport specialization		.03
Moderate	1.46 (0.97-2.18)	.07
High	1.46 (0.97-2.18)	.07

[a]Reference levels for categorical variables: female sex (male), degree of sport specialization (low), weekly organized sports hours exceeding age (no). BMI, body mass index; OR, odds ratio.