

Injury Risk Associated With Sports Specialization and Activity Volume in Youth

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Background: Sports specialization has become increasingly common among youth.

Purpose/Hypothesis: To investigate the relative importance of specialization vs volume of activity in increasing risk of injury. Hypotheses were that specialization increases the risk of injury and that risk varies by sport.

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

Methods: A prospective analysis was conducted with data collected from 10,138 youth in the Growing Up Today Study—a prospective cohort study of youth throughout the United States—and their mothers. Activity was assessed via questionnaires in 1997, 1998, 1999, and 2001. Sports specialization was defined as engaging in a single sport in the fall, winter, and spring. Injury history was provided by participants' mothers via questionnaire in 2004. The outcome was incident stress fracture, tendinitis, chondromalacia patella, anterior cruciate ligament tear, or osteochondritis dissecans or osteochondral defect.

Results: Females who engaged in sports specialization were at increased risk of injury (hazard ratio [HR], 1.31; 95% CI, 1.07-1.61), but risk varied by sport. Sports specialization was associated with greater volume of physical activity in both sexes ($P < .0001$). Total hours per week of vigorous activity was predictive of developing injury, regardless of what other variables were included in the statistical model (males: HR, 1.04; 95% CI, 1.02-1.06; females: HR, 1.06; 95% CI, 1.05-1.08). Among females, even those engaging in 3 to 3.9 hours per week less than their age were at a significantly increased risk of injury (HR, 1.93; 95% CI, 1.34-2.77). In males, there was no clear pattern of risk.

Conclusion: Sports specialization is associated with a greater volume of vigorous sports activity and increased risk of injury. Parents, coaches, and medical providers need to be made aware of the volume threshold above which physical activity is excessive.

Keywords: epidemiology; prospective cohort study; sex-based differences; adolescents

Although many youth in the United States do not meet the US guidelines for physical activity,⁹ various recent reviews and position statements warn that a subset of youth is engaging in excessive training and sports specialization.^{2,8,12,13,15} In a 2016 consensus statement, the AOSSM suggested that early sports specialization may increase risk of injury and burnout, with no evidence to support that specializing early leads to success in the sport at an elite level.¹⁴ Despite the American Academy of Pediatrics publishing in 2000 the first position statement in an effort to reduce the possibility of injuries,⁷ an insufficient number of studies have examined the topic. Moreover, there is a lack of prospective studies examining the risk of injury among population-based samples of adolescents.

The AOSSM describes sports specialization as engaging in a sport for at least 8 months per year (approximately 3

seasons per year) at the exclusion of other sports.¹⁴ Parents and coaches are believed to be the drivers of the trend toward intensive training in a single sport beginning early in life, especially in swimming and gymnastics.^{1,5} Although physical activity is essential for healthy mental and physical growth, too much activity can cause injuries that may have long-term consequences.¹⁴ In middle- and high-income communities, sports and vacation camps, travel and club teams, and competitions at young ages are widely available and may appeal to parents and youth who believe that early specialization will confer a benefit in terms of getting into secondary schools or college. In addition, it is often believed that this specialization will be beneficial in securing college scholarships and membership on elite collegiate, national, Olympic, or professional teams.^{4,5}

Relatively few studies have examined sports specialization in youth, and none have been very large (>5000 people) prospective studies, with some studies including only cases.^{8,12} Furthermore, the results of prior studies have not

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been entirely consistent, which may reflect differences in study design and samples. One cross-sectional study of students from 2 high schools found that athletes who reported playing 1 sport for >8 months of the year were more likely to have a history of knee injury, but the authors found no difference in injury prevalence between athletes who played 1 sport and those who played multiple sports.^{8,12} However, a case-control study of 1190 preadolescents and adolescents found that injured youth were older and engaged in more hours of activity than controls. Furthermore, independent of these factors, youth who specialized in a sport were significantly more likely than their peers to sustain an overuse injury.³ The results from a nested case-control study of 351 soccer players¹⁷ were more nuanced. Females who played on another soccer team had double the risk of a knee injury, but there was not a significant difference in the risk of knee injuries among females who had played on another sports team in the past month. However, females who engaged in other forms of physical activity were significantly less likely to develop a knee injury. The results suggest that volume or intensity of activity may be a confounder, since females who play on multiple soccer teams tend to be on very competitive teams, whereas, there is a wide range of intensity to engaging in activity that is not as part of a sports team. In other words, volume of activity is associated with specialization and is strongly predictive of injury, even among those who do not specialize. Therefore, not adjusting for volume in the model makes specialization appear to have a stronger association with injury, because some of the effect is due to volume rather than specialization per se. Of note, the rate of repeat injury was higher than the rate of first injury.

A recent systematic review of sport specialization in youth found that only 2 retrospective cohort studies and 1 case-control study met its inclusion and exclusion criteria.⁸ The authors concluded that evidence on the consequences of early sport specialization is scarce and shows only modest associations with sport specialization. A more recent systematic review and meta-analysis⁵ of 1 prospective and 4 retrospective studies concluded that specialization was associated with increased risk of injury. Although it was an excellent synthesis of the current literature, what is now needed are prospective studies that stratify per history of injury or focus exclusively on first injury.

The goal of our investigation was to examine whether youth who specialize in a sport are at increased risk of injury and whether any specific sports are particularly high in risk. In other words, we were seeking to determine whether the risk of injuries varies by sport. Our other goal

was to examine how the number of hours per week of training was associated with injury risk and whether it partially explained the associations between sports specialization and injury risk. In addition, we sought to examine whether the number of hours per week of vigorous activity was related to risk regardless of whether the youth specialized in a sport.

METHODS

Overview

The Growing Up Today Study (GUTS) was established by recruiting the children of registered nurses participating in the Nurses' Health Study II (NHS II). A detailed letter was sent to NHS II participants in 1996 who had children between the ages of 9 and 14 years. The purposes of GUTS were explained, and nurses were asked to provide parental consent for their children to enroll. Additional details have been reported.¹⁰ Approximately 68% of the females (n = 9039) and 58% of the males (n = 7843) returned completed questionnaires, thereby assenting to participate in the cohort. The GUTS project, including the analyses with data from GUTS participants and their mothers in NHS II, was approved by the Human Subject Committee at Brigham and Women's Hospital.

Measures

From the fall of 1996 through 2003, the GUTS participants received a questionnaire every 12 to 18 months assessing a variety of factors. Self-reported weight and height were assessed on all questionnaires. Menstrual status was assessed annually from 1996 through 2005. Females were asked whether their menstrual periods had started. Females who marked "yes" were asked the age at which periods began (age at menarche). Body mass index (kg/m²) was calculated with self-reported weight and height information. Children were classified as overweight or obese per the cutoffs of the International Obesity Task Force,⁶ which are age- and sex-specific and provide comparability in assessing overweight and obesity from adolescence to adulthood. The validity of self-reported weight and height among preadolescents and adolescents has been investigated by several groups of researchers, and the results show that young people provide valid information on weight and height.^{11,19,20}

In 1997, 1998, 1999, and 2001, seasonal patterns in physical activity were assessed with 18 questions for females

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Ethical approval for this study was obtained from the Partners Human Research Committee.

and 19 for males on hours per week within each of the 4 seasons that a participant engaged in a specific activity (eg, volleyball or soccer). Football was included as a sport on the male questionnaire but not the female one. Mean hours per week engaged in a specific sport was computed as the mean hours in that activity in the summer, fall, winter, and spring. Hours per week of moderate and vigorous activity were computed as the sum of mean hours per week engaged in any of the following sports: basketball, baseball, biking, dance/aerobics, hockey, running, swimming, skating, skateboarding, soccer, tennis, football (males only), cheerleading/gymnastics, weightlifting, volleyball, and karate. Reporting of a mean of >40 hours per week was considered implausible and therefore set to missing and not used in the analysis. Sport specialization was defined as engaging in a specific sport in all 3 seasons of the traditional school year (fall, winter, and spring) and not engaging in any other sports for multiple seasons. We created variables to indicate whether a participant engaged in a specific activity for 3 seasons (eg, soccer), allowing us to examine risks with injury varied by specific activity. Hours per week of vigorous activity was computed as the sum of mean hours per week engaged in any of the following sports: basketball, dance/aerobics, hockey, running, swimming, skating, soccer, tennis, football (males only), cheerleading/gymnastics, volleyball, and karate. All activity variables were time dependent, so the sports specialization status and activity volume used in the model were from the year prior to the reported injury or end of follow-up, whichever came first.

To examine whether the association between volume and risk of injury varied by age, we created a series of indicator variables for hours of vigorous activity in relation to age. For example, someone who was 13 years old and engaged in 16 hours of vigorous activity was assigned a value of 3.

Outcome

The outcome was incident stress fracture, tendinitis, osteochondritis dissecans or osteochondral defect, chondromalacia patella/patella femoral syndrome, or anterior cruciate ligament (ACL) tear. In 2004, the mothers of the GUTS participants, who are registered nurses participating in the ongoing NHS II, were sent a brief questionnaire. They were asked whether a doctor has ever diagnosed their child with any of the following conditions: stress fracture, chondromalacia patella or patella femoral syndrome, tendinitis, ACL tear, or osteochondritis dissecans or osteochondral defect. If the mother indicated that her child had a history of 1 of the conditions, she was asked to report the age at diagnosis. Cases were defined as GUTS participants whose mothers reported that they were diagnosed with a stress fracture, chondromalacia patella or patella femoral syndrome, tendinitis, ACL tear, or osteochondritis dissecans or osteochondral defect at an age older than when they entered the GUTS cohort in the fall of 1996. Children who were the same age at diagnosis and entry into GUTS were classified as prevalent cases and not included in the analysis. Reports of injury without an age at diagnosis were excluded from

the analysis, since it would be impossible to know whether the cases occurred in the eligible time frame.

Sample

GUTS participants were eligible for the analyses if they completed ≥ 1 questionnaire and their mothers provided information on the 2004 questionnaire about their history of orthopaedic conditions. Participants were excluded if their mothers reported that their injury occurred in 1997 (164 females, 92 males), the GUTS participant did not provide plausible information (>40 hours per week; 101 females, 174 males), or there was missing information on physical activity (7 females, 16 males). After these exclusions, 4384 males and 5754 females aged 10 to 16 years in 1997 remained for analysis.

Data Analysis

All analyses were conducted in 2018 using SAS statistical software (v 9.4; SAS Institute). Cox proportional hazards models were used for all multivariate analyses. Statistical models were controlled for age or were stratified by age group. Body mass index or weight status and age at menarche were considered as possible confounders. Several models were used to investigate whether specialization per se, specialization in specific sports, or total volume of vigorous activity was predictive of developing an orthopaedic injury. In the model examining whether specialization in a specific sport increased risk, indicator variables for specialization (yes/no) in each sport were included in the same model. In secondary analyses, we evaluated the risk of developing tendinitis, chondromalacia patella, stress fracture, and ACL tear in separate models. To examine whether the association between volume and risk of injury varied by age, we created a series of indicator variables for hours of vigorous activity in relation to age. Volume within 1 year of age was considered the referent and set to zero. All P values are 2-sided, with $P < .05$ considered statistically significant.

RESULTS

Between 1997 and 2003, approximately 18% ($n = 1178$) of females and 15% of males ($n = 793$) sustained at least 1 overuse injury or an ACL tear or were diagnosed with osteochondritis dissecans/osteochondral defect. Tendinitis was the most common injury and had the largest sex-based difference in prevalence (Figure 1). Osteochondritis dissecans/osteochondral defect was the least common injury. Among males, age was unrelated to risk, whereas among females, risk of injury significantly decreased with age ($P = .006$). The risk of injury was similar for youth who were overweight or obese and those who were leaner ($P = .4$ for females and $P = .5$ for males). In addition, age at menarche was not related to injury ($P = .9$).

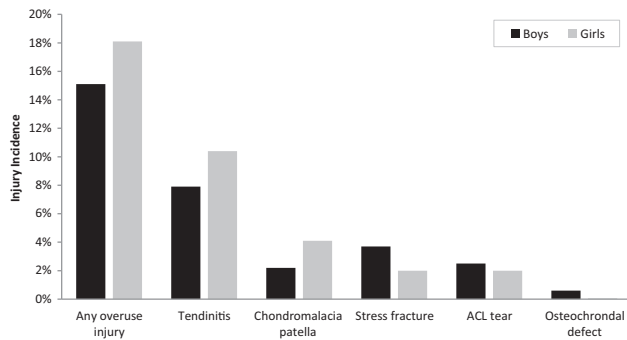


Figure 1. Cumulative incidence of sports injuries, anterior cruciate ligament (ACL) tear, or osteochondritis dissecans or osteochondral defect for the first time among 4307 boys and 5706 girls in Growing Up Today Study (1997-2004).

TABLE 1
Demographics at Baseline (1997) Among Youth in the Growing Up Today Study and Rates of Sports Specialization Over Time^a

	Males (n = 4307)	Females (n = 5706)
Age, y	12.4 ± 1.6	12.6 ± 1.6
Body mass index, kg/m ²	19.9 ± 3.6	19.7 ± 3.5
Weight status		
Overweight	18.0	13.5
Obese	4.6	3.4
Engage in 1 sport for >3 seasons		
1997	58.4	58.7
1998	56.8	59.5
1999	57.2	59.0
2001	53.8	56.3

^aValues are presented as mean ± SD or percentage.

Sports Specialization

In 1997, approximately 58% of participants engaged in 1 sport for ≥ 3 seasons. Rates decreased over time, particularly among males (Table 1). Youth who engaged in sport specialization were at increased risk of injury (females: hazard ratio [HR], 1.69; 95% CI, 1.41-2.03; males: HR, 1.50; 95% CI, 1.18-1.90). However, when hours per week of vigorous activity was also included in the model, the association with specialization was attenuated (females: HR, 1.31; 95% CI, 1.07-1.61) and no longer significant among the males (HR, 1.19; 95% CI, 0.90-1.58). In age-adjusted analyses, males who specialized in baseball or gymnastics/cheerleading had double the risk of their peers of developing an injury (Table 2). The results were similar when hours per week of vigorous activity was included in the model. In contrast, among females in age-adjusted analyses, specialization in running, swimming, soccer, and cheerleading/gymnastics all were independently predictive of higher risk of injury, and there was a suggestion that specialization in volleyball also increased risk. However, after controlling for hours per week of vigorous activity, the

results were attenuated, and no associations were significant.

Volume of Activity

Hours per week of vigorous activity was a significant predictor of subsequent injury regardless of whether specialization was included in the model. Males and females who specialized in a sport engaged in significantly more vigorous physical activity ($P < .0001$). Among both males and females, mean hours per week engaged in vigorous activity was predictive of a higher risk of injury (males: HR, 1.04; 95% CI, 1.02-1.06; females: HR, 1.06; 95% CI, 1.05-1.08). The risk, however, was not uniform across all types of activity. Hours per week engaged in running, basketball, soccer, and cheerleading/gymnastics was predictive of an increased risk of injury among both males and females (Table 3). In addition, among males, hours per week engaged in baseball (HR, 1.11; 95% CI, 1.05-1.18) was associated with increased risk, as was volleyball (HR, 1.07; 95% CI, 1.02-1.13) among the females.

In terms of total volume of vigorous activity, females—even those engaging in 3 to 3.9 hours per week less than their age (eg, a 16-year-old female engaged in 13 hours per week of vigorous activity)—were at a significantly increased risk of injury (HR = 1.93; 95% CI, 1.34-2.77) (Table 4). In males, there was not a clear pattern of risk.

DISCUSSION

We observed that most youth were engaging in a specific sport for ≥ 3 seasons, but the percentage declined over time as the cohort aged, which is consistent with the findings of McGuine et al¹⁶ for youth in 29 high schools in Wisconsin. We found that among >11,000 youth throughout the United States, overuse injuries and ACL tears are relatively common, particularly among females. Overall, youth who specialize in sports are at increased risk of injury, but contrary to our expectations, we did not find females who specialize in any particular sport to be at higher risk of injury after we took volume of activity into consideration. The patterns in males were slightly different and suggest that males who specialize in baseball or gymnastics/cheerleading may be more likely than their peers to develop overuse injuries.

Similar to Jayanthi et al,¹³ we observed that total hours per week engaged in vigorous activity was a robust predictor of risk. However, in contrast to their findings, we found that sport specialization was a weaker predictor of risk, particularly among females. There are several reasons for the difference in results. First, the definition of specialization was different in the 2 studies. Second, in both studies, participants reported their activity patterns via questionnaire, but in our study, the reports were prior to injury, whereas in the study by Jayanthi et al, participants reported after the injury and thus were more likely to be biased. Third, the composition of the cases likely varied between the studies. In our study, tendinitis was the most common injury. A patient with tendinitis may not necessarily be referred to a specialist clinic. Jayanthi et al¹³

TABLE 2
Prospective Association Between Sports Specialization and Risk of Injury Among Adolescents and Young Adults in the Growing Up Today Study^a

≥3 Seasons Engaged In . . .	Males		Females	
	Model 1: Age	Model 1 + h/wk of Vigorous Activity	Model 1: Age	Model 1 + h/wk of Vigorous Activity
Running	1.13 (0.87-1.49)	0.87 (0.65-1.17)	1.39 (1.14-1.70)	1.09 (0.88-1.36)
Basketball	1.30 (0.99-1.70)	1.02 (0.76-1.37)	1.15 (0.89-1.50)	0.89 (0.68-1.17)
Baseball	2.01 (1.23-3.30)	2.21 (1.35-3.63)	1.10 (0.60-2.01)	1.10 (0.60-2.01)
Dance	0.54 (0.20-1.47)	0.57 (0.21-1.54)	1.00 (0.82-1.21)	1.00 (0.83-1.22)
Swimming	0.70 (0.40-1.23)	0.59 (0.33-1.03)	1.39 (1.05-1.83)	1.10 (0.83-1.47)
Skating	0.70 (0.42-1.17)	0.56 (0.33-0.94)	1.02 (0.71-1.46)	0.88 (0.61-1.25)
Soccer	1.47 (1.06-2.04)	1.11 (0.79-1.58)	1.40 (1.07-1.84)	1.02 (0.76-1.36)
Football	0.69 (0.48-1.01)	0.58 (0.40-0.85)	—	—
Tennis	0.98 (0.55-1.76)	0.85 (0.47-1.53)	0.64 (0.35-1.16)	0.51 (0.28-0.92)
Volleyball	1.25 (0.46-3.38)	1.40 (0.52-3.79)	1.37 (0.98-1.92)	1.37 (0.97-1.92)
Martial arts	1.38 (0.87-2.20)	1.10 (0.69-1.78)	0.58 (0.26-1.29)	0.48 (0.21-1.08)
Hockey	1.07 (0.65-1.76)	0.82 (0.49-1.37)	1.35 (0.72-2.56)	1.00 (0.52-1.90)
Cheerleading/gymnastics	3.33 (1.46-7.58)	2.70 (1.18-6.17)	1.54 (1.17-2.02)	1.21 (0.91-1.61)

^aValues are presented as hazard ratio (95% CI). Data are from Cox proportional hazards models that included all the activities listed in the table, which were measured in the cycle before case designation: 1178 females and 793 males developed a stress fracture, chondromalacia patella or patella femoral syndrome, tendinitis, anterior cruciate ligament tear, or osteochondritis dissecans or osteochondral defect for the first time.

TABLE 3
Prospective Age-Adjusted Association Between Hours per Week Engaged in Specific Sports and Risk of Injury Among Adolescents and Young Adults in the Growing Up Today Study^a

Hours per Week	Males	Females
Running	1.07 (1.01-1.12)	1.08 (1.04-1.13)
Basketball	1.05 (1.00-1.11)	1.06 (1.02-1.11)
Baseball	1.11 (1.05-1.18)	1.02 (0.96-1.08)
Dance	0.93 (0.73-1.19)	1.02 (0.98-1.06)
Swimming	0.98 (0.91-1.05)	1.04 (1.00-1.09)
Skating	0.96 (0.86-1.07)	1.01 (0.94-1.09)
Soccer	1.07 (1.02-1.12)	1.07 (1.02-1.11)
Football	1.00 (0.95-1.07)	—
Tennis	1.03 (0.91-1.15)	1.00 (0.93-1.09)
Volleyball	1.11 (0.92-1.35)	1.07 (1.02-1.13)
Martial arts	1.08 (0.99-1.16)	0.93 (0.77-1.12)
Hockey	1.02 (0.93-1.12)	1.04 (0.95-1.13)
Cheerleading/gymnastics	1.21 (1.09-1.34)	1.09 (1.04-1.14)

^aValues are presented as hazard ratio (95% CI). Data are from Cox proportional hazards models that included all the activities listed in the table, which were measured in the cycle before case designation: 1178 females and 793 males developed a stress fracture, chondromalacia patella or patella femoral syndrome, tendinitis, anterior cruciate ligament tear, or osteochondritis dissecans or osteochondral defect for the first time.

recruited their cases from 2 hospital-based sports medicine clinics. Thus, their cases may have contained more severe overuse injuries than other studies. Our injury mix was also somewhat different from that observed by McGuine et al¹⁶ among high school athletes.

In that sample,¹⁶ sprains and strains were the most common injury types, with the authors observing no difference

TABLE 4
Prospective Age-Adjusted Association Between Hours per Week of Vigorous Activity and Risk of Injury Among Adolescents and Young Adults in the Growing Up Today Study^a

	Males	Females
Vigorous activity, h/wk, in relation to age		
≥4 less than age	Referent	Referent
3-3.9 h less than age	1.78 (1.12-2.83)	1.93 (1.34-2.77)
2-2.9 h less than age	2.10 (1.32-3.34)	1.82 (1.22-2.74)
1-1.9 h less than age	1.32 (0.67-2.58)	1.90 (1.18-3.05)
Hours = age	2.26 (1.36-3.78)	2.24 (1.40-3.60)
1-1.9 h more than age	1.41 (0.70-2.87)	2.00 (1.13-3.56)
2-2.9 h more than age	1.05 (0.43-2.56)	2.89 (1.69-4.93)
3-3.9 h more than age	2.32 (1.22-4.38)	2.16 (1.07-4.34)
≥4 more than age	1.20 (0.79-1.81)	1.58 (1.05-2.39)

^aValues are presented as hazard ratio (95% CI). Data are from Cox proportional hazards models in which 1178 females and 793 males developed a stress fracture, chondromalacia patella or patella femoral syndrome, tendinitis, anterior cruciate ligament tear, or an osteochondritis dissecans or osteochondral defect for the first time.

between moderate and low specialization, but those participants in the high specialization group were significantly more likely to sustain an injury over the year. We did not assess sprains or strains in our study, which might partially explain the difference in findings. Another possible reason for the difference is that McGuine et al¹⁶ adjusted for activity volume as a binary variable, whether or not an athlete was exceeding recommendations. While that is an important piece of information for conveying results to coaches and athletic trainers, when one dichotomizes a

continuous variable, it can result in substantial residual confounding. In other words, because there is a substantial range in volume between the group below and above the recommendations, the analysis may still be partially confounded by volume. It is difficult to compare our results with previous cross-sectional studies¹⁶ and studies including only cases, since our methods were different in that we focused on incident injuries and collected information on activity before injury (ie, not subject to recall bias).

Limitations and Strengths

It is important to be aware of our study's limitations and strengths. Our data were collected via self-report; thus, there is likely some measurement error. Since the injuries were reported by the mothers, who are registered nurses, and the activity data were reported by the GUTS participants, the errors in reporting activity should be unrelated to errors in reporting injury. However, we do not have information on the participants' levels of participation. Another limitation is that our sample is >90% Caucasian; thus, it is not known whether the results are generalizable to youth of other races/ethnicities. Also, we did not collect information on all possible overuse injuries. Despite these limitations, there are numerous strengths to the study. Our sample was large and included youth throughout the United States. Another unique strength is that we examined specialization overall, as well as sport-specific specialization. Moreover, we used a population-based sample; as such, the results should be generalizable to a wide variety of youth. Since previous injuries strongly predict future injuries, our focus on initial injuries is an important strength and ensures that the results are not confounded by injury history.

What is clear across our study, as well as in previous large case-control studies, is that youth who are engaged in sport specialization have a higher volume of activity. In our study, this predicted among females an increased risk of developing an injury for the first time. Others have found that these youth are more likely to have sustained past injuries and are at increased risk of chronic injuries.¹⁸ Taken together, the results clearly show that a high volume of activity, which is more common among youth who specialize in a sport, should be avoided.

Implications and Contributions

Our results suggest more than simply recommending that youth engage in more than 1 sport or do not engage in 1 sport for multiple seasons. We also need a cultural change on the norms of physical activity in our society: We need fewer hours of practice for young athletes overall.

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