

Epidemiology of Pediatric Gymnastics Injuries Reported in US Emergency Departments

Sex- and Age-Based Injury Patterns

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Background: Despite increasing participation rates in youth gymnastics, the majority of epidemiologic literature focuses on older elite athletes or stratifies athletes by level of competition.

Hypothesis: The authors hypothesized that sex- and age-based patterns in youth gymnastics-related injuries exist, which are otherwise overlooked in an unstratified population.

Study Design: Descriptive epidemiology study.

Methods: Publicly available injury data from the National Electronic Injury Surveillance System were collected on pediatric gymnastics injuries presenting to emergency departments in the United States. Participation data from the National Sporting Goods Association were used to calculate national injury incidence rates in 7- to 11-year-olds (childhood) and 12- to 17-year-olds (adolescence) from January 1, 2012, to December 31, 2018. Z tests were conducted for the comparison of injury rates between girls and boys within each age group and for overall injury rate across age groups.

Results: Girls participated in gymnastics at a frequency 6.5 times that of boys in childhood and 13.5 times that of boys in adolescence. An estimated 72,542 youth gymnastics-related injuries were reported in US emergency departments each year. A large proportion (61.3%) occurred in childhood, with female predominance in both age groups. Overall, there was no difference in weighted annual injury rate (injuries per 100,000 athlete-days per year) by age group (6.9 [childhood] vs 8.8 [adolescence]; $P = .19$) or sex (7.4 [girls] vs 8.1 [boys]; $P = .65$). In adolescence, boys were more likely than girls to experience injury (16.47 vs 8.2; $P = .003$). Wrist and lower arm fractures were more common in childhood than adolescence (1.07 vs 0.43; $P = .002$) and specifically in girls (childhood vs adolescence, 1.06 vs 0.37; $P = .001$). Ankle injuries and concussions were more common in adolescence vs childhood ($P = .01$ and $.0002$).

Conclusion: Upper extremity injuries predominated among childhood gymnasts, particularly girls. In adolescence, girls and boys experienced increases in concussions and foot and ankle injuries. Although representing a lower overall number of training gymnasts as compared with girls, adolescent boys experience a higher rate of injuries overall.

Keywords: gymnastics; youth; injury; epidemiology; male; female

In the United States, participation in gymnastics increased substantially in the years surrounding 2010, with a greater emphasis on opportunities for young athletes.³⁶ Of the nearly 4.8 million participants in gymnastics in 2019, 49% were between the age of 6 and 12 years.¹⁰ Gymnastics has the youngest age of single-sport specialization at 8.9 years and is among the few sports, along with figure skating and diving, in which early specialization has been associated with attainment of elite competition at higher rates.^{19,24}

The maneuvers in competitive gymnastics inherently expose athletes to injury risk. The National Collegiate Athletic Association reports an injury rate in gymnastics second only to wrestling, and this rate surpasses football.^{13,14} In the broader competitive population, including high school, club, and collegiate gymnasts, injury rates are 0.05 to 1.5 per participant season or 0.5 to 1.3 per 1000 hours of sport-specific exposure.³⁻⁸ Younger age and participation in noncompetitive settings have been associated with lower injury risk.^{17,21,26,32}

Epidemiologic studies reveal trends in injury patterns. Most gymnastics injuries occur during practice, rather than in competition, and with increased frequency toward

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the beginning of a season.^{3,9,13} Tumbling passes (eg, roundoff, handspring) during the floor exercise and dismounts from an apparatus account for 50% to 70% of all injuries.^{13,15,16,18,21,26,40} A 2019 systematic review stated that all studies involving female gymnasts reported a higher incidence of lower extremity injury, but the 2 studies that included male athletes identified the upper extremity as the most commonly affected location.⁵

Artistic gymnastics events vary in discipline by sex. While floor exercise and vault are common disciplines between the sexes, there are 2 more events for women (balance beam and uneven bars) and 4 for men (rings, parallel bars, high bar, and pommel horse). Westermann et al⁴² described a 10-year experience of male and female Division I collegiate gymnasts with sex-specific injury patterns. Rates of injury were higher for women than men, with 9.7 and 8.8 per 1000 athlete-exposures respectively, and female collegiate gymnasts were >2 times as likely to require surgery. The authors reiterated the discrepancy in common injury sites, finding foot and ankle injuries to be most common in women versus hand and wrist in men.

The current literature largely focuses on elite gymnastics at the collegiate or national level rather than younger, immature athletes.^{5,13} Competitive club teams, which include these younger athletes, are usually reported as a whole group or stratified by class of competition. While this methodology may account for specific competition skills and associated risks, it may not adequately examine associations influenced by skeletal and motor development that trends with chronologic age. Age- and sex-based variations in incidence and injury characteristics provide valuable data regarding sport-specific risk and may allow for the development of targeted injury prevention. Such successful programs have been implemented for the prevention of throwing injuries in youth baseball players and anterior cruciate ligament injuries in female adolescent soccer players after both populations were identified as high risk for injury in previous epidemiological studies.^{6,30,31}

The purpose of this study was to examine gymnastics-related injuries in the pediatric population and to describe differences in injury prevalence at different ages for male and female athletes. We hypothesized that sex- and age-based patterns in youth gymnastics-related injuries exist and are otherwise overlooked in an unstratified population.

METHODS

This study was deemed exempt from institutional review board approval, as the data were nonidentifiable and obtained from public sources.

National Electronic Injury Surveillance System

Injury data were obtained from the National Electronic Injury Surveillance System (NEISS), which is a publicly available database operated by the US Consumer Product Safety Commission (CPSC).²⁷ The NEISS provides a nationwide probability sample of injuries based on US emergency department (ED) visits from a network of approximately 100 hospitals. Participating hospitals are grouped into strata, 4 of which are based on hospital size (at least 6 beds) and ED visits (24-hour ED) and 1 of which consists of children's hospitals. Trained coders from the CPSC review the ED records daily and enter injury information into the NEISS, at which point each case is assigned a code that designates activities corresponding to the injury. Each case is also assigned a statistical weight that is determined by the inverse of the probability of selection for the hospitals in each stratum, which allows for the calculation of nationwide injury estimates. Studies have demonstrated NEISS data to be reliable for the description of nonfatal injuries in the United States.^{20,35}

National Sporting Goods Association

Participation (exposure) data were obtained from the 2019 sports participation report of the National Sporting Goods Association (NSGA).³⁶ The NSGA survey results are based on approximately 34,000 individuals aged ≥ 7 years. The data were weighted to represent the demographic composition of the United States based on the state of residence, household income, and population density. The NSGA survey results estimate the number of participants and frequency of participation (number of days) in each sport by sex and age. This allows for the calculation of the total number of "athlete-days." The NSGA sports participation report was utilized for this study, as it includes overall sports participation trends by demographics (sex and age) and has been implemented in previous literature.²³

Participants

The NEISS was used to identify the study cohort as those individuals who sustained gymnastics-related injuries

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Ethical approval was not sought for the present study.

treated in an ED from January 1, 2012, to December 31, 2018. The database was queried for participants aged 7 to 17 years to coincide with available exposure data from the NSGA report. The data set included the following: sex (male, female), age (7-17 years), gymnastics athletes (organized, recreational), body part (eg, head, finger, knee, ankle), diagnosis (eg, dislocation, strain/sprain, fracture, concussion), disposition (eg, not admitted to hospital, admitted to hospital, fatalities), and narrative (free-text description of injury from treating provider entered by CPSC coder). The database did not specify the level of participation or discipline of gymnastics (eg, artistic, rhythmic, trampoline, acrobatic). Exposure data from the NSGA report group participants into 7- to 11-year-olds and 12- to 17-year-olds, which we categorized as the childhood and adolescence groups, respectively. The NSGA report was used to identify gymnastics participants within these age groups corresponding to the same NEISS sample period (January 1, 2012-December 31, 2018).

Statistical Analysis

Sample weights were assigned to each NEISS case by NEISS coders based on the inverse probability of being selected, which allows for calculation of national injury estimates. Frequency distributions were calculated for sex and age groups for the 5 most common gymnastics-related injuries (body part and diagnosis). Patterns by sex and age group (childhood vs adolescence) were examined utilizing Pearson chi-square tests and 95% confidence intervals. Injury rates are reported as annual number of injuries per 100,000 exposures (athlete-days) calculated with the use of provided statistical weights. Exposure (denominator) data from the NSGA 2019 sports participation report were used. Certain injuries (eg, head internal injury and concussion) were combined for analyses as a result of their similarities and overlap in reporting in the NEISS (ie, numerous

injuries labeled head internal injury had a narrative specifying a diagnosis of concussion). The statistical weights for each NEISS case were used to calculate the national injury number per diagnosis (weighted averages), which was then incorporated with participation data and annualized to obtain the weighted annual injury rates, adjusted for participation. Z tests were conducted for the comparison of injury rates between girls and boys within each age group and overall injury rate across age groups. The analyses were performed using SAS (Version 9.4; SAS Institute). Statistical significance was defined a priori as $P < .05$ for all statistical analyses.

RESULTS

Over a 7-year period from 2012 to 2018, the mean annual number of 7- to 17-year-old patients who presented to NEISS-participating US EDs for gymnastics-related injuries was 2652. After using the associated statistical weights, this number was adjusted to an estimate of 72,542 gymnastics-related injuries nationally per year. The majority of patients presenting with injuries were treated and released (96.6%, or 70,084 estimated injuries per year), while only 2.1% were treated and admitted for hospitalization. The remaining patients were categorized as treated and transferred to another hospital, left without being seen, and held for observation. Participation data in athlete-days per year within this period are presented in Table 1. Participation was higher in the childhood group in both sexes, while it was higher for girls than boys in both age groups.

The childhood group accounted for 61.3% of all injuries (44,485 estimated injuries per year), and the adolescence group accounted for 38.7% of injuries (28,057 estimated injuries per year) (Table 2). Total injury rates (all body locations and diagnoses combined) were not significantly different between age groups (Table 3). Girls accounted for 88.4% of all injuries (39,315 estimated injuries per year) in the childhood group and 87.1% of all injuries (24,431 estimated injuries per year) in the adolescence group; boys accounted for the remaining 11.6% (5170 estimated injuries per year) and 12.9% (3626 estimated injuries per year), respectively. Overall, there was no significant sex-based difference in injury rates. While there was no sex-based difference in the childhood group, boys had a significantly higher injury rate than girls in the adolescence group ($P < .01$).

TABLE 1
Athlete-Days of Participation per Year ($\times 100,000$) From 2019 NSGA Report^a

	Childhood (Age 7-11 y)	Adolescence (Age 12-17 y)
Female	800.45	425.74
Male	123	31.45

^aExposure (denominator) data from the NSGA 2019 sports participation report³⁶ were used. NSGA, National Sporting Goods Association.

TABLE 2
Estimated Number of Gymnastics-Related Injuries Treated per Year in US Emergency Departments, 2012-2018

	No. of Injuries per Year (No. of Injuries per 100,000 Athlete-Days)		
	Childhood (Age 7-11 y)	Adolescence (Age 12-17 y)	Total
Female	39,315 (49)	24,431 (57)	63,746 (52)
Male	5170 (42)	3626 (115)	8796 (57)
Total	44,485 (48.2)	28,057 (61.4)	72,542 (53)

TABLE 3

Estimated Weighted Rate of Gymnastics-Related Injuries Treated per Year in US Emergency Departments, 2012-2018

	No. of Injuries per 100,000 Athlete-Days (95% CI)	Weighted Injury Rate per Year	<i>P</i>
Age group			.19
Childhood (7-11 y)	48.2 (34.9-61.5)	6.9	
Adolescence (12-17 y)	61.4 (47.0-75.7)	8.8	
Sex			.65
Female	52.0 (38.5-65.5)	7.4	
Male	57.0 (40.6-73.3)	8.1	

TABLE 4

Most Common Diagnoses and Calculated Injury Estimates Across All Age Groups

Diagnosis	Injury Estimate, No. (% of Total Injuries)
Ankle strain/sprain	8845 (12.19)
Lower arm fracture	6040 (8.33)
Wrist strain/sprain	4778 (6.59)
Head internal injury	3103 (4.28)
Knee strain/sprain	2915 (4.02)
Neck strain/sprain	2898 (3.99)
Foot strain/sprain	2869 (3.95)
Finger fracture	2780 (3.83)
Head concussion	2414 (3.33)
Wrist fracture	2255 (3.11)
Elbow strain/sprain	2234 (3.08)
Elbow fracture	2177 (3.00)
Foot contusion/abrasion	2057 (2.84)
Finger strain/sprain	1687 (2.30)
Other (remaining diagnoses)	25,490 (35.14)

The 14 most common diagnoses and calculated injury estimates across both age groups are listed in Table 4. These diagnoses accounted for an estimated 47,052 injuries per year (65%), while none of the remaining diagnoses individually accounted for >3% of total injuries. The remaining diagnoses composed the “other” category and included injuries such as upper trunk fracture and lower trunk strain/sprain. Accordingly, the remainder of the analysis on sex and age patterns focused on these 14 most common diagnoses.

Several of the most common diagnoses affecting the same body location, with overlap in reporting, were combined into categories for injury rate comparisons: head internal injury and head concussion (concussion), foot strain/sprain and ankle strain/sprain (foot and ankle strain/sprain), wrist fracture and lower arm fracture (wrist and lower arm fracture), finger strain/sprain and finger fracture (finger strain/sprain/fracture), and elbow strain/sprain and elbow fracture (elbow strain/sprain/fracture). This resulted in 9 diagnosis categories for the sex-based comparison (Table 5) and age-based comparison (Table 6).

Childhood Gymnastics Injuries

During childhood, girls presented with a similar injury rate as compared with boys (7.02 vs 6.00; $P = .49$). Wrist/lower arm fracture was a more frequent presentation in childhood than adolescence (1.07 vs 0.43; $P = .002$).

Adolescent Gymnastics Injuries

During adolescence, boys had a significantly higher overall injury rate as compared with girls (16.47 vs 8.2; $P = .003$). Injuries for adolescent gymnasts more commonly involved ankle and foot strain/sprain, by a factor of 1.92 ($P = .01$). Concussion was also more frequently a presenting complaint during adolescence than childhood, by a factor of 3.18 ($P = .0002$). The concussion injury rate in adolescence was 5.11 times higher in boys ($P = .03$) and 2.97 times in girls ($P = .001$) than in childhood (Table 6).

DISCUSSION

In the period from 2012 to 2018, an estimated 2652 athletes were treated annually in US NEISS EDs for gymnastics-related injuries, which extrapolates to 72,542 gymnast injuries annually, based on national sports participation data. In childhood (7-11 years), boys and girls had similar injury rates (6.0 vs 7.02, respectively; $P = .49$), but female athletes presented with a significantly greater number of elbow injuries (0.45 vs 0.09; $P = .003$) and finger injuries (0.55 vs 0.16; $P = .005$) than their male counterparts. In adolescence (12-17 years), male athletes had a higher overall injury rate than their female counterparts (16.47 vs 8.2; $P = .003$). Ankle and foot strain/sprain (adolescence/childhood, 1.92; $P = .01$) and concussions (adolescence/childhood, 3.18; $P = .0002$) were more common in adolescence than in childhood, but wrist and lower arm fracture (adolescence/childhood, 0.40; $P = .002$) was more common in childhood versus adolescence.

Using historical data without sex-based comparisons, Singh et al³⁴ evaluated emergency room visits for gymnastics injuries from 1990 to 2005 and reported a national estimate of 26,000 injuries annually. The 3-fold increase in annual ED visits in our current study may reflect the national uptrend in youth sports and youth gymnastics participation. While the previous study cited increasing injuries with age, the contemporary data demonstrate an equivalent rate of injury in the younger population. The propensity for upper extremity injuries in the childhood subset and lower extremity in the adolescence group has not changed.³⁴

The majority of published studies, which notably source injury reports from patient surveys or team-affiliated physician or athletic trainer records, cite the lower extremities as the most common site of injury in gymnasts.^{3,4,7,13,21,25,32} However, Singh et al, similar to this current work, reported upper extremity injuries to be most common in younger, childhood gymnasts presenting to the ED. This same age-specific trend was demonstrated in cheerleaders as well, who perform similar tumbling skills to gymnasts.³³ Most

TABLE 5
Weighted Rate of All Gymnastics-Related Injuries by Sex^a

Diagnosis	Overall	Female	Male	P
Childhood (age 7-11 y)				
Ankle and foot strain/sprain	0.93	0.93 (0.57-1.29)	0.88 (0.41-1.36)	.87
Concussion	0.33	0.31 (0.21-0.41)	0.51 (0.00-0.86)	.28
Wrist and lower arm fracture	1.07	1.06 (0.68-1.44)	1.11 (0.51-1.72)	.89
Elbow strain/sprain/fracture	0.40	0.45 (0.25-0.64)	0.09 (0.00-0.22)	.003
Finger strain/sprain/fracture	0.50	0.55 (0.34-0.77)	0.16 (0.00-0.33)	.005
Knee strain/sprain	0.22	0.24 (0.13-0.36)	0.10 (0.08-0.28)	.18
Wrist strain/sprain	0.48	0.52 (0.30-0.74)	0.21 (0.00-0.48)	.08
Neck strain/sprain	0.25	0.25 (0.13-0.37)	0.27 (0.00-0.53)	.92
Foot contusion/abrasion	0.25	0.22 (0.12-0.33)	0.40 (0.00-0.71)	.29
All gymnastics injuries	6.88	7.02 (5.02-9.02)	6.00 (3.97-8.04)	.49
Adolescence (age 12-17 y)				
Ankle and foot strain/sprain	1.79	1.78 (1.18-2.38)	1.92 (0.43-3.40)	.87
Concussion	1.05	0.92 (0.59-1.26)	2.76 (0.00-4.70)	.07
Wrist and lower arm fracture	0.43	0.37 (0.19-0.56)	1.27 (0.00-2.32)	.10
Elbow strain/sprain/fracture	0.57	0.55 (0.32-0.77)	0.91 (0.00-1.92)	.48
Finger strain/sprain/fracture	0.38	0.35 (0.18-0.52)	0.85 (0.06-1.76)	.29
Knee strain/sprain	0.46	0.41 (0.21-0.62)	1.05 (0.00-2.07)	.23
Wrist strain/sprain	0.53	0.53 (0.34-0.72)	0.46 (0.00-1.05)	.82
Neck strain/sprain	0.39	0.37 (0.18-0.56)	0.65 (0.00-1.42)	.49
Foot contusion/abrasion	0.15	0.13 (0.00-0.26)	0.35 (0.00-1.00)	.63
All gymnastics injuries	8.77	8.20 (6.10-10.29)	16.47 (11.35-21.59)	.003

^aData are presented as No. of injuries per 100,000 athlete-days (95% CI). Bold P values indicate statistically significant sex-based difference within the age group (P < .05).

TABLE 6
Weighted Rate of Adolescent Gymnastics-Related Injuries Relative to Childhood, Overall and by Sex^a

Diagnosis	Overall	P	Female	P	Male	P
Ankle and foot strain/sprain	1.92	.012	1.91	.02	2.18	.19
Concussion	3.18	.0002	2.97	.001	5.11	.03
Wrist and lower arm fracture	0.40	.0021	0.35	.001	1.15	.80
Elbow strain/sprain/fracture	1.43	.26	1.22	.51	10.11	.11
Finger strain/sprain/fracture	0.76	.36	0.64	.15	5.31	.15
Knee strain/sprain	2.09	.06	1.71	.16	10.50	.07
Wrist strain/sprain	1.10	.74	1.02	.94	2.19	.74
Neck strain/sprain	1.56	.20	1.48	.29	2.41	.35
Foot contusion/abrasion	0.60	.31	0.59	.90	0.86	.52
All gymnastics injuries	1.28	.19	1.17	.43	2.75	.0002

^aBold P values indicate statistically significant difference versus childhood (P < .05).

other studies, which focused on elite competitors, largely excluded this childhood group. Young athletes, attempting to quickly assimilate gymnastics skills while developing maturation-based strength and coordination, may place significant stress through poorly supported or positioned wrists and elbows. Additionally, off-balance falls may be more frequent, resulting in young gymnasts reaching out with their arms to brace themselves, which may predispose them to upper extremity injuries.²² These injuries may be traumatic and require ED presentation, which may further explain their relative rates in these studies as compared with those examining older gymnasts.

Some studies have reported a sex-specific component to injury location, isolating the most common injury in male

gymnasts to be to the upper extremity, particularly the wrist and hand.^{5,39,42} This was not replicated in our study, as upper extremity injuries were universal in the childhood group, with elbow and finger injuries being even more common for young female athletes. Biomechanical data indicate that forces about the elbow uniquely predispose young female athletes to injury while performing basic tumbling skills such as cartwheels and roundoffs.⁸ Potential contributing factors could be discrepant strength, size, biomechanics, specific skills, or intensity of training; further investigation regarding female susceptibility for these upper extremity injuries as compared with their male counterparts is warranted.

In the older gymnastics, adolescent girls demonstrated a higher incidence of foot and ankle sprains/strains, in

keeping with the established trend reported across the literature.^{3,7,13,21,25,32,39} At the same time, upper extremity injury rates significantly dropped in female gymnasts as compared with the high risk seen in childhood. It seems that young female gymnasts may transition from upper extremity risk during falls or uneven upper body weight-bearing during childhood to lower extremity landing injury as age and skills advance. With advancing talent and ability, older gymnasts are performing more challenging skills with presumably higher-impact dismounts transmitting marked force through the lower extremities, which has been shown to be the phase or action most associated with injury.^{1,13,15,16,18,21,26,40} Additionally, postpubertal female gymnasts are at risk for amenorrhea as part of the female athlete triad, leading to decreased bone mineral density, which can also predispose athletes to injury.^{28,37,38}

While previous literature suggests a higher injury rate with increasing age and level of competition, in this contemporary cohort, this trend was demonstrated only among male gymnasts, who had a higher injury rate in the adolescence group.^{16,17,21,26,32} There was no statistical difference in overall injury risk for female gymnasts by age. It may be possible that the wrist, arm, and elbow injury rate that is higher in the younger female group is responsible for this finding.

In the decades surrounding the year 2000, the female US Olympic gymnasts experienced significant success and wide popularity. From the 1984 to 2016 Olympics, female US gymnasts won 28 gold medals and 86 medals overall. The increase in female participation and exposure to advanced specialized training, often with greater intensity and frequency, at an early age may have resulted in higher rates of female arm and elbow injuries in this young age group.^{12,29,37} While beyond the scope of the current study, investigation of these trends and training methods on this higher volume of female child gymnasts is warranted.

Finally, concussion was seen in male and female adolescent players at higher rates than in previous studies and at increasing rates in adolescence. These injuries were 7.6% of all gymnastics injuries presenting to the ED in our cohort, a significant increase from the 1.7% reported by Singh et al³⁴ over a decade prior. This trend was mirrored across other youth sports in the same time frame.² While this may be due to increased sports participation, it may also represent increased awareness of concussive symptoms as promoted by safety and prevention initiatives.^{11,41}

Limitations

The limitations of this study largely pertain to the utilization of the NEISS database for injury surveillance. National data are an extrapolated population estimate from hospital-based EDs, rather than a census of all types of EDs. Although efforts were made to obtain nationally representative injury and participation data, both reporting systems' employed weighted samples and may be subject to further sampling bias. There is also the possibility that medical coding may not be accurately representative of the associated narrative description of the injury. Furthermore, combined injury groups used for analysis may

overlook subtle nuances that may have been evident with individual analysis. By utilizing an ED-based injury database, it is possible to overlook injuries presenting to a free-standing urgent care, managed by an athletic trainer at the training facility, or treated symptomatically at home, as well as subacute or chronic injuries that may have instead presented directly to a physician's office (eg, gymnast wrist, capitellar osteochondritis dissecans, shoulder impingement, spondylolysis, ankle instability). Additionally, use of the database in this manner does not distinguish formal gymnastics training from recreational gymnastics injuries, which may occur at school or at home. Last, the NSGA report utilized only days in sport over the study period; therefore, this may not accurately reflect hours of training per day or training intensity, as is the more preferred way of reporting the incidence rate per exposure. Additionally, the exposure data are not specific to the injury cohort, but rather, the NSGA exposures are applied to the extrapolated NEISS injuries both representing national averages.

CONCLUSION

Study findings indicated that in the United States, age- and sex-based patterns exist in youth gymnastics-related injuries, which may otherwise be overlooked in an unstratified population. Upper extremity injuries predominate among childhood athletes, particularly girls. In adolescence, girls and boys experience increases in concussions and foot and ankle injuries. While representing a lower overall number of training gymnasts as compared with girls, adolescent boys experience a higher rate of injuries overall. Identification of these risks allows for development of age- and sex-specific targeted injury prevention programs for young gymnasts.

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