

[Primary Care]

Timing of Lower Extremity Injuries in Competition and Practice in High School Sports

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Background: Laboratory-based experiments demonstrate that fatigue may contribute to lower extremity injury (LEI). Few studies have examined the timing of LEIs during competition and practice, specifically in high school athletes across multiple sports, to consider the possible relationship between fatigue and LEIs during sport events.

Hypothesis: The purpose of this study was to describe the timing of LEIs in high school athletes within games and practices across multiple sports, with a hypothesis that more and severe injuries occur later in games and practices.

Study Design: Descriptive epidemiologic study.

Level of Evidence: Level 4.

Methods: Using the National High School RIO (Reporting Information Online) sport injury surveillance system, LEI severity and time of occurrence data during practice and competition were extracted for 9 high school sports.

Results: During the school years 2005-2006 through 2013-2014, 16,967,702 athlete exposures and 19,676 total LEIs were examined. In all sports surveyed, there was a higher LEI rate, relative risk for LEI, and LEI requiring surgery during competition than practice. During practice, the majority of LEIs occurred over an hour into practice in all sports. In quarter-based competition, more LEIs occurred in the second (31% to 32%) and third quarters (30% to 35%) than in the first (11% to 15%) and fourth quarters (22% to 26%). In games with halves, the majority (53% to 66%) of LEIs occurred in the second half. The greater severity LEIs tended to occur earlier in games.

Conclusion: Fatigue may play a role in the predominance of injuries in the second half of games, though various factors may be involved. Greater severity of injuries earlier in games may be because of higher energy injuries when athletes are not fatigued.

Clinical Relevance: These findings can help prepare sports medicine personnel and guide further related research to prevent LEIs.

Keywords: fatigue; injury; adolescent athletes; lower extremity

More than 7.5 million US high school athletes participated in sports during the 2012-2013 school year.¹⁸ Despite acknowledged advantages to participation in sports, injuries are an important concern for high school athletes because of immediate and long-term physical effects, missed school days, practice and competition

time, and psychological and financial burdens.¹⁴ Using various methods, research has attempted to evaluate the role that fatigue plays in sports injuries. One common method to assess this possible link between fatigue and injury has been the intentional creation of fatigue through exercise followed by observation of joint biomechanics on completing plyometric

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The authors report no potential conflicts of interest in the development and publication of this article. The content of this report provided by the High School Reporting Information Online (RIO) surveillance system was funded in part by the Centers for Disease Control and Prevention (grant No. R49/CE000674-01 and R49/CE001172-01). The content of this manuscript is solely the responsibility of authors and does not represent the official views of the Centers for Disease Control and Prevention. The author responsible for High School RIO, R.D.C., also acknowledges the generous research funding contributions of the National Federation of State High School Associations, National Operating Committee on Standards for Athletic Equipment, DonJoy Orthotics, and EyeBlack.

DOI: 10.1177/1941738116685704

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movements such as landing from drop jumps. Throughout these studies, the changes in joint biomechanics with fatigue have been used to estimate risk of injury.^{10,13,16,17,25,27} Utilizing these suboptimal research methods, most of these studies indicate that fatigue increases injury risk.^{16,25,26} Studies have assessed the risk of injury in relation to time of play during competition and practice in a single sport.^{22,30}

The purpose of this study was to describe the timing of lower extremity injuries (LEIs) in high school athletes across multiple sports. The hypotheses were that (1) injuries would be more common later in practice and competition when athletes were likely more fatigued and (2) injuries sustained later in practice or competition would be more severe than injuries sustained earlier in practice or competition.

METHODS

This study was approved by the Institutional Review Board at Nationwide Children's Hospital, Columbus, Ohio, and at the Colorado Multiple Institutional Review Board, Aurora, Colorado.

Data Collection

Data were collected using the National High School Sports-Related Injury Surveillance System, High School RIO (Reporting Information Online), an internet-based sports injury surveillance system described previously.^{2,19} In brief, high schools with 1 or more National Athletic Trainers' Association-affiliated certified athletic trainer (AT) with valid email address were invited to participate. Interested high schools were categorized into 8 strata based on school population (enrollment ≤ 1000 or >1000) and US Census geographic region.²⁸ For the 9 sports originally included in the High School RIO study (football, boys' and girls' soccer, girls' volleyball, boys' and girls' basketball, wrestling, baseball, and softball), 100 high schools were randomly selected to participate (12 or 13 from each of the 8 strata). If a school dropped out of the study, a replacement from the same stratum was randomly selected to maintain the 100-school study population. For the additional 11 sports added to the High School RIO study since 2008 (girls' field hockey, girls' gymnastics, boys' ice hockey, boys' and girls' lacrosse, boys' and girls' track and field, boys' and girls' swimming and diving, boys' volleyball, and cheerleading), not enough schools from each of the 8 strata offered all sports. Thus, exposure and injury data for these sports were collected from a convenience sample of US high schools with ATs. If an AT from a convenience sample school also reported information for athletes in 1 of original 9 sports, these data were included in the overall convenience sample dataset but were not included in weighted national estimates.

Study Definitions

High School RIO defined athlete exposure (AE) as 1 athlete participating in 1 practice or competition. A reportable injury (1) occurred from participation in organized practice, competition, or performance (cheerleading only); (2) required medical attention by an AT or physician; and (3) resulted in

restriction of the athlete's participation for 1 or more days. ATs reported weekly AEs by sport throughout the academic year. In this study, injuries that resulted in >3 weeks of time loss before return to play or resulted in medical disqualification were considered severe. Throughout the study, reporters could view previously submitted information and update reports as needed.

This study evaluated only LEIs and only included 9 sports: boys' and girls' basketball, boys' and girls' lacrosse, boys' and girls' soccer, football, boys' ice hockey, and girls' field hockey. These sports were selected based on movement patterns, field of play, and division of playing time into discrete periods.

Statistical Analysis

Data were analyzed using SAS version 9.4 (SAS Institute), and injury rates were calculated as the number of injuries per 10,000 AEs. Injury rate ratios (RRs) were calculated with 95% confidence intervals (CIs). CIs not including 1.00 were considered statistically significant. The following is an example of the RR calculation:

$$RR = \frac{\text{No. of total AEs for girls} / \text{No. of LEIs sustained by girls}}{\text{No. of total AEs for boys} / \text{No. of LEIs sustained by boys}}$$

RESULTS

Injury Rates

From 2005-2006 through 2013-2014, there were 19,676 total LEIs sustained during 16,967,702 AEs in the sports included in the study, resulting in a rate of 11.6 LEIs per 10,000 AEs. Of these LEIs, 1843 resulted in surgical repair. The overall LEI rate was highest in football (15.2 per 10,000 AEs), followed by girls' soccer (13.9) and girls' basketball (10.3), and lowest in boys' ice hockey (4.8) (Table 1). While football also had the highest rate of competition-related LEIs (47.6 per 10,000 competition AEs), followed by girls' soccer (28.8), and girls' basketball (18.2), girls' field hockey had the lowest rate (8.9). In each sport, the rate of LEI was significantly higher in competition compared with practice.

The rate of LEIs resulting in surgery followed the same pattern, with the highest overall rate in football (1.5) followed by girls' soccer (1.4) and girls' basketball (1.2), and the highest competition rate in football (5.8), followed by girls' soccer (3.7) and girls' basketball (2.6) (Table 1). Again, in each sport the rate of LEIs resulting in surgery was significantly higher in competition compared with practice.

In sex-comparable sports, LEI rates were significantly higher among girls compared with boys in basketball (RR, 1.2; 95% CI, 1.2-1.3) and soccer (RR, 1.5; 95% CI, 1.4-1.6). There was no difference between LEI rates in girls' and boys' lacrosse (RR, 1.0; 95% CI, 0.9-1.1), although this is not generally considered a sex-comparable sport given the vast differences in rules and protective equipment.

Table 1. Rates of lower extremity injuries by sport, National High School Sports-Related Injury Surveillance Study, United States, 2005–2006 through 2013–2014^a

Sport	No. of All Lower Extremity Injuries (% of All Injuries)	No. of AEs	Rate (per 10,000 AEs)	RR (95% CI) ^b	No. Lower Extremity Injuries Resulting in Surgery (% of All Lower Extremity Injuries)	No. of AEs	Rate (per 10,000 AEs)	RR (95% CI) ^b
Boys' basketball total	2235 (53.2)	2,680,389	8.3		140 (6.3)	2,680,389	0.5	
Competition	1075 (25.6)	800,766	13.4	2.2 (2.0-2.4)	81 (7.5)	800,766	1.0	3.2 (2.3-4.5)
Practice	1160 (27.6)	1,879,623	6.2		59 (5.1)	1,879,623	0.3	
Girls' basketball total	2236 (54.8)	2,160,536	10.3		256 (11.4)	2,160,536	1.2	
Competition	1193 (29.2)	656,725	18.2	2.6 (2.4-2.9)	171 (14.3)	656,725	2.6	4.6 (3.5-6.0)
Practice	1043 (25.6)	1,503,811	6.9		85 (8.1)	1,503,811	0.6	
Boys' lacrosse total	498 (35.2)	662,960	7.5		58 (11.6)	662,960	0.9	
Competition	253 (17.7)	203,574	12.4	2.3 (1.9-2.8)	38 (15.0)	203,574	1.9	4.3 (2.5-7.4)
Practice	245 (17.5)	459,386	5.3		20 (8.2)	459,386	0.4	
Girls' lacrosse total	362 (51.5)	481,687	7.5		42 (11.6)	481,687	0.9	
Competition	158 (22.4)	149,792	10.5	1.7 (1.4-2.1)	33 (20.9)	149,792	2.2	8.1 (3.9-17.0)
Practice	204 (29.1)	331,895	6.1		9 (4.4)	331,895	0.3	
Boys' soccer total	2110 (52.8)	2,225,836	9.5		132 (6.3)	2,225,836	0.6	
Competition	1202 (30.1)	667,804	18.0	3.1 (2.8-3.4)	101 (8.4)	667,804	1.5	7.6 (5.1-11.4)
Practice	908 (22.8)	1,558,032	5.8		31 (3.4)	1,558,032	0.2	
Girls' soccer total	2639 (57.3)	1,900,452	13.9		259 (9.8)	1,900,452	1.4	
Competition	1663 (36.1)	576,995	28.8	3.9 (3.6-4.2)	211 (12.7)	576,995	3.7	10.1 (7.4-13.8)
Practice	976 (21.2)	1,323,457	7.4		48 (4.9)	1,323,457	0.4	
Football total	8986 (37.2)	5,929,294	15.2		918 (10.2)	5,929,294	1.5	
Competition	4813 (20.0)	1,010,148	47.6	5.6 (5.4-5.8)	583 (12.1)	1,010,148	5.8	8.5 (7.4-9.7)
Practice	4173 (17.3)	4,919,146	8.5		335 (8.0)	4,919,146	0.7	

(continued)

Table 1. (continued)

Sport	No. of All Lower Extremity Injuries (% of All Injuries)	No. of AEs	Rate (per 10,000 AEs)	RR (95% CI) ^b	No. Lower Extremity Injuries Resulting in Surgery (% of All Lower Extremity Injuries)	No. of AEs	Rate (per 10,000 AEs)	RR (95% CI) ^b
Boys' ice hockey total	172 (20.7)	356,997	4.8		14 (8.1)	356,997	0.4	
Competition	121 (14.6)	117,764	10.3	4.8 (3.5-6.7)	12 (9.9)	117,764	1.0	12.2 (2.7-54.5)
Practice	51 (6.1)	239,233	2.1		2 (3.9)	239,233	0.1	
Girls' field hockey total	438 (44.3)	569,551	7.7		24 (5.5)	569,551	0.4	
Competition	160 (16.2)	180,038	8.9	1.2 (1.0-1.5)	13 (8.1)	180,038	0.7	2.6 (1.1-5.7)
Practice	278 (28.1)	389,513	7.1		11 (4.0)	389,513	0.3	

AE, athlete exposure; CI, confidence interval; RR, rate ratio.

^aGirls' field hockey, boys' ice hockey, and girls' and boys' lacrosse were included only from 2008-2009 through 2013-2014, when those sports were included in the database.

^bRate ratio comparing competition rates to practice rates (referent category).

Table 2. Top 3 most commonly injured body parts, injury diagnoses, and specific injuries of all lower extremity injuries by sport, National High School Sports-Related Injury Surveillance Study, United States, 2005-2006 through 2013-2014^a

Sport	Body Part Injured (%)	Injury Diagnosis (%)	Specific Injury (%)
Boys' basketball			
1	Ankle (64.0)	Sprains/strains (78.7)	Ankle sprains/strains (61.3)
2	Knee (22.0)	Contusion (7.7)	Knee sprains/strains (10.1)
3	Thigh/upper leg (8.0)	Fracture (3.1)	Thigh/upper leg sprains/strains (4.5)
Girls' basketball			
1	Ankle (51.6)	Sprains/strains (77.4)	Ankle sprains/strains (49.9)
2	Knee (33.2)	Contusion (5.7)	Knee sprains/strains (18.0)
3	Thigh/upper leg (7.7)	Tendonitis (3.8)	Thigh/upper leg sprains/strains (6.7)
Boys' lacrosse			
1	Knee (33.2)	Sprains/strains (69.2)	Ankle sprains/strains (27.2)
2	Ankle (29.4)	Contusion (13.9)	Knee sprains/strains (19.5)
3	Thigh/upper leg (20.2)	Tendonitis (3.8)	Thigh/upper leg sprains/strains (15.2)
Girls' lacrosse			
1	Ankle (37.1)	Sprains/strains (77.6)	Ankle sprains/strains (34.8)
2	Knee (27.6)	Contusion (3.9)	Knee sprains/strains (17.0)
3	Thigh/upper leg (18.1)	Tendonitis (6.9)	Thigh/upper leg sprains/strains (16.4)
Boys' soccer			
1	Ankle (35.4)	Sprains/strains (67.7)	Ankle sprains/strains (30.9)
2	Knee (26.3)	Contusion (16.6)	Thigh/upper leg sprains/strains (18.6)
3	Thigh/upper leg (23.1)	Fracture (4.6)	Knee sprains/strains (13.7)
Girls' soccer			
1	Ankle (37.7)	Sprains/strains (73.2)	Ankle sprains/strains (34.5)
2	Knee (33.4)	Contusion (11.8)	Knee sprains/strains (20.4)
3	Thigh/upper leg (17.2)	Tendonitis (3.0)	Thigh/upper leg sprains/strains (15.1)
Football			
1	Knee (39.9)	Sprains/strains (73.2)	Ankle sprains/strains (30.8)
2	Ankle (33.8)	Contusion (13.7)	Knee sprains/strains (24.5)
3	Thigh/upper leg (15.1)	Fracture (6.0)	Thigh/upper leg sprains/strains (10.1)
Boys' ice hockey			
1	Knee (43.0)	Sprains/strains (44.8)	Knee sprains/strains (18.0)
2	Thigh/upper leg (27.3)	Contusion (32.0)	Thigh/upper leg contusion (14.5)
3	Ankle (18.6)	Fracture (7.6)	Ankle sprains/strains (14.5)
Girls' field hockey			
1	Knee (31.2)	Sprains/strains (68.1)	Thigh/upper leg sprains/strains (25.7)
2	Thigh/upper leg (28.2)	Contusion (11.9)	Ankle sprains/strains (22.7)
3	Ankle (24.5)	Tendonitis (6.0)	Knee (13.9)

^aGirls' field hockey, boys' ice hockey, and girls' and boys' lacrosse were included only from 2008-2009 through 2013-2014, when those sports were included in the database. Results show percent of all lower extremity injuries within each sport.

Body Part, Type, and Specific Diagnoses of Injuries

The ankle, knee, and thigh/upper leg were the top 3 most frequently injured body sites for most sports (Table 2). For all

sports, sprains/strains and contusions were the most frequent diagnoses of injury. Ankle sprains/strains were the most common specific injury for all sports except boys' ice hockey (knee sprain/strain) and girls' field hockey (thigh/upper leg sprain/strain).

Table 3. Time in play during which lower extremity injuries occurred by sport, National High School Sports-Related Injury Surveillance Study, United States, 2005-2006 through 2013-2014^a

Sport	Time in Competition				Time in Practice				
	Quarters →	First, n (%)	Second, n (%)	Third, n (%)	Fourth, n (%)	<1 Hour Into Practice, n (%)	1-2 Hours Into Practice, n (%)	>2 Hours Into Practice, n (%)	
Boys' basketball		77 (10.9)	217 (30.8)	244 (34.7)	166 (23.6)	425 (38.8)	607 (55.4)	64 (5.8)	
Girls' basketball		83 (10.6)	248 (31.5)	268 (34.1)	187 (23.8)	381 (39.5)	529 (54.8)	55 (5.7)	
Boys' lacrosse		28 (12.3)	72 (31.7)	69 (30.4)	58 (25.5)	88 (39.5)	107 (48.0)	28 (12.6)	
Football		484 (15.3)	1008 (31.8)	976 (30.8)	704 (22.2)	1167 (29.8)	2287 (58.4)	464 (11.8)	
Halves →	First, n (%)	Second, n (%)							
Boys' soccer	264 (34.1)	511 (65.9)		333 (39.5)		448 (53.1)		63 (7.5)	
Girls' soccer	416 (38.0)	680 (62.0)		341 (37.6)		515 (56.7)		52 (5.7)	
Girls' lacrosse	66 (46.8)	75 (53.2)		80 (45.7)		80 (45.7)		15 (8.6)	
Girls' field hockey	54 (38.3)	87 (61.7)		96 (37.9)		135 (53.4)		22 (8.7)	
Periods →	First, n (%)	Second, n (%)	Third, n (%)						
Boys' ice hockey	32 (28.1)	50 (43.9)	32 (28.1)		17 (38.6)		23 (52.3)		4 (9.1)

^aGirls' field hockey, boys' ice hockey, and girls' and boys' lacrosse were included only from 2008-2009 through 2013-2014, when those sports were included in the database.

Timing of Injuries During Practice and Competition

The majority of injuries in practice occurred >1 hour into practice for all sports (Table 3). During competition for sports divided into halves (boys' and girls' soccer, girls' lacrosse and girls' field hockey), more than half (53% to 66%) of all injuries occurred in the second half. In sports played in quarters, more injuries occurred in the second (31% to 32%) and third quarters (30% to 35%) than in the first (11% to 15%) and fourth quarters (22% to 26%). In these quarter-based sports, when the injuries in quarters were combined into halves, 42% to 47% of LEIs occurred in the first half and 53% to 58% occurred during the second half of competitions. In boys' ice hockey, the only sport with games divided into 3 periods, 44% of injuries occurred in the second period and 28% of the injuries occurred in both the first and third periods.

Severity of Injuries by Time in Competition and Practice

The severity of injury based on time to return to play tended to be lower later in games (Table 4). A greater percentage of injuries occurring in the earliest portion of games (ie, the first quarter, half, or period) resulted in >3 weeks of time loss before

return to play or resulted in medical disqualification. However, this association was statistically significant only in boys' soccer (odds ratio [OR], 1.6; 95% CI, 1.03-2.38) and football (OR, 1.6; 95% CI, 1.27-2.09). There were no identifiable patterns between the severity of injuries and the time during practice that they occurred. A greater percentage of injuries occurring later in games resulted in <1 week of time out of play in all sports except girls' lacrosse.

DISCUSSION

In recent years, neuromuscular fatigue has been discussed as a contributing factor to LEIs in competitive athletes, specifically the anterior cruciate ligament of the knee.^{11,15,26} Various studies have examined the relationship between injury rates and fatigue in both competition and practice,^{1,3,6,8,9,20,21,23,30} concluding that the lower leg is the most frequent site of overuse injury.^{6,8,9,12,21,23}

Overall, the highest LEI rates were in football, followed by girls' soccer, girls' basketball, and boys' basketball. This is consistent with High School RIO reports comparing overall injury rates across sports, which annually identify the highest injury rates in football with a rate of 3.87 injuries per 1000 AEs.⁴ Also consistent with past studies reporting overall injury

Table 4. Severity of competition-related lower extremity injury by time in play during which they were sustained by sport, National High School Sports-Related Injury Surveillance Study, United States, 2005-2006 through 2013-2014^a

Time of Injury During Competition	Severity of Injury by Time to Return to Play				
	<1 Week, n (%)	1-3 Weeks, n (%)	> 3 Weeks, n (%)	Medical DQ, n (%)	Other ^b , n (%)
Boys' basketball					
First quarter	28 (38.4)	21 (28.8)	7 (9.6)	6 (8.2)	11 (15.1)
Second quarter	82 (38.7)	72 (34.0)	20 (9.4)	14 (6.6)	24 (11.3)
Third quarter	102 (43.2)	71 (30.1)	19 (8.1)	12 (5.1)	32 (13.6)
Fourth quarter	70 (43.5)	61 (37.9)	8 (5.0)	3 (1.9)	19 (11.8)
Girls' basketball					
First quarter	23 (29.5)	25 (32.1)	6 (7.7)	9 (11.5)	15 (19.2)
Second quarter	77 (32.4)	93 (39.1)	16 (6.7)	24 (10.1)	28 (11.8)
Third quarter	96 (36.6)	91 (34.7)	17 (6.5)	28 (10.7)	30 (11.5)
Fourth quarter	59 (32.4)	60 (33.0)	13 (7.1)	17 (9.3)	33 (18.1)
Boys' lacrosse					
First quarter	9 (33.3)	8 (29.6)	2 (7.4)	5 (18.5)	3 (11.1)
Second quarter	28 (38.9)	19 (26.4)	3 (4.2)	15 (20.8)	7 (9.7)
Third quarter	33 (48.5)	17 (25.0)	4 (5.9)	7 (10.3)	7 (10.3)
Fourth quarter	33 (57.9)	10 (17.5)	2 (3.5)	4 (7.0)	8 (14.0)
Girls' lacrosse					
First half	26 (43.3)	11 (18.3)	3 (5.0)	10 (16.7)	10 (16.7)
Second half	21 (28.0)	26 (34.7)	4 (5.3)	7 (9.3)	17 (22.7)
Boys' soccer					
First half	91 (36.1)	80 (31.8)	21 (8.3)	26 (10.3)	34 (13.5)
Second half	225 (45.7)	146 (29.7)	28 (5.7)	37 (7.5)	56 (11.4)
Girls' soccer					
First half	119 (29.8)	134 (33.6)	26 (6.5)	58 (14.5)	62 (15.5)
Second half	266 (41.0)	198 (30.5)	39 (6.0)	52 (8.0)	94 (14.5)
Football					
First quarter	135 (29.5)	132 (28.8)	40 (8.7)	66 (14.4)	85 (18.6)
Second quarter	351 (36.1)	310 (31.9)	74 (7.6)	94 (9.7)	144 (14.8)
Third quarter	376 (40.2)	266 (28.4)	73 (7.8)	82 (8.8)	139 (14.9)
Fourth quarter	265 (39.0)	202 (29.8)	61 (9.0)	47 (6.9)	104 (15.3)
Boys' ice hockey					
First period	12 (40.0)	9 (30.0)	3 (10.0)	3 (10.0)	3 (10.0)
Second period	18 (38.3)	17 (36.2)	6 (12.8)	4 (8.5)	2 (4.3)
Third period	18 (58.1)	5 (16.1)	5 (16.1)	2 (6.5)	1 (3.2)
Girls' field hockey					
First half	28 (51.9)	15 (27.8)	3 (5.6)	3 (5.6)	5 (9.3)
Second half	44 (53.0)	23 (27.7)	3 (3.6)	4 (4.8)	9 (10.8)

DQ, disqualification.

^aGirls' field hockey, boys' ice hockey, and girls' and boys' lacrosse were included only from 2008-2009 through 2013-2014, when those sports were included in the database.

^bIncludes the following conditions: season ended before athlete returned to activity, athlete chose not to continue (no medical disqualification), and athlete released from team (no medical disqualification).

patterns, LEI rates in the current study were significantly higher in competition compared with practice.^{3,6,8,9,20,29} Previous studies found that 52% of injuries among British football academy athletes occurred during practice,³ and nearly twice as many injuries occurred in competition versus practice among British youth football players.⁹ Injuries observed by High School RIO found a rate of 4.31 injuries per 1000 AEs in competition versus 1.34 injuries per 1000 AEs for practice.⁴ Potential explanations could include intense play, physical contact with other players, unanticipated events, and less player risk aversion during competitions. Additionally, practice sessions include noncontact or partial-contact activities, limiting AEs to full-contact activities.³⁰ Across all sports, a higher proportion of LEIs occurred >1 hour into practice. This finding may be due to scrimmages and other game-simulation activities most often occurring during the second half of practice, while warm-up and drills dominate the earlier portion of practices. The low proportion of injuries occurring >2 hours into practice may be attributable to few practices at the high school level exceeding 2 hours.

The highest proportion of LEIs occurred in the middle 2 quarters (girls' and boys' basketball, boys' lacrosse, and football), the second period (boys' ice hockey), and the second half (girls' lacrosse, girls' field hockey, boys' and girls' soccer) of games. In quarter-based games, when data were collapsed from quarters into halves, it was also found that a greater proportion of LEIs happened in the second half of games. In previous studies, there was an apparent decrease in lower leg kinematics and an increase in injury rates in the second halves of games or simulated practices.^{5,21,24,25} Other studies that included specific data on timing within halves of soccer games showed increased incidence of injury in the middle third and last portions of each half.^{3,8,9,21} The High School RIO dataset did not allow more precise analysis (ie, the dataset does not include minute of injury) during halves. The evaluation of quarter-based sports in this study did not support this timing of injury pattern. Instead, the highest proportion of LEIs occurred in the middle of games played in quarters. A previous study on American football found a similar pattern of a higher injury incidence in the second and third quarters.²⁹

Similar to other studies, the rates of LEIs requiring surgery were higher during competition than practice.^{6,7,9,30} Injuries in competition were more severe, requiring surgery more often and resulting in greater return to play times. The breakdown of severity of injuries incurred within competition was unexpected. Despite the low proportion of all LEIs in the first quarter, a higher proportion of LEIs requiring surgery occurred in this quarter compared with others. LEIs incurred in the first half of half-based sports resulted in longer return to play times than LEIs sustained at other times in games.

As with all studies, this study has limitations. The High School RIO sample is limited to high schools with ATs, which limits generalizability. It is possible that athletes did not report some injuries to their AT because of self-treatment or unwillingness to report, which would result in slight underestimates of these LEI

rates. Additionally, because AEs were unit- rather than time-based, neither could participation/exposure rates be reported by minute or hour of practice and competition nor could occurrence of injury be evaluated by minute in competition. Failing to assess the real playing time of each player restricts the power to draw firm conclusions regarding the associations found between fatigue and LEI rates and severity.

The epidemiologic data obtained from this study should advance the understanding of LEIs among high school athletes and also provide insight into the timing of these injuries as an initial step into population-based evaluations of the role fatigue plays. Given the relative frequency of LEIs in athletic populations, the goal should be to prevent these injuries when possible and reduce the severity of LEIs that cannot be prevented.

ACKNOWLEDGMENT

The authors thank Ariel Kiyomi Lepon, BA. Acknowledgment also goes to the hundreds of certified athletic trainers who have reported data to High School Reporting Information Online. Without their dedication, this dataset would not exist.

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