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Descriptive Epidemiology of High School Swimming and Diving Injuries

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Structured Abstract

Objective: Using data from a longitudinal national sports injury surveillance program, this study aimed to calculate injury rates and describe injury patterns across high school swimmers and divers.

Design: Descriptive Epidemiological Study. Athletic trainers (ATs) from participating high schools reported injuries from swimming and diving programs for the High School Reporting Information Online system.

Setting: Convenience sample of high school boys and girls swimming and diving injuries during the 2008–2019 school years.

Patients or other Participants: High school boys and girls swimmers and divers (aged ~14–18 years).

Independent Variables: Exposure data on gender, location of injury (practice versus competition), mechanism of injury, and sport (swimming versus diving).

Main Outcome Measures: Injury rates, rate ratios with 95% confidence intervals (CIs), and other descriptive statistics were performed.

Results: 563 swimming and diving injuries occurred during 2,171,260 athlete exposures (0.26 per 1000 athlete exposures). Girls had higher injury rates than boys overall (rate ratio (RR) 1.57, $p < 0.05$), in practice (RR 1.53, $p < 0.05$), and competition (RR 1.81, $p < 0.05$). In swimmers, most injuries were to the shoulder (48.6%), associated with the freestyle (67.3%), and classified as overuse/chronic (58.0%). Amongst divers, most injuries were to the head/face (36.6%) and from contact with the playing surface (68.3%).

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Conclusions: Girls had statistically significantly higher injury rates than boys. The shoulder and head/face were the most injured body parts in swimmers and divers, respectively. Swimming injuries were most frequently of an overuse etiology, while diving injuries were more likely traumatic. Coaches and ATs should be aware of these findings to develop targeted strategies for injury prevention.

Keywords

Swimming; diving; epidemiology; injuries; adolescents

Introduction

High school swimming and diving is a fast-growing high school sport in the United States, with participation increasing over 8% between 2008–2018.[1] While participation has risen, the scope of research with respect to swimming and diving injuries in the adolescent age group remains limited. Previous studies have described the epidemiology of swimming and diving injuries at the collegiate level,[3–7] demonstrating higher frequency of injury to the shoulder and/or upper arm, most often classified as overuse or non-contact, as well as differences with regard to gender and age. For example, female college swimmers have higher overuse injury rates than males; [3,5,6] college freshmen have the highest incidence of injury, attributed to an abrupt increase in training volume.[7] Literature evaluating diving injuries is more limited. College divers have been found to have a higher overall injury rate than college swimmers, the greatest proportion of those injuries being to the head or face. [3,5]

While valuable in providing context for general injury patterns in swimmers and divers, these studies were limited by sample size and generalizability. For example, two of these studies examined only a single program, one of which is followed data from a single season.[4,7] More recently, Trinidad et al. performed a systematic review to describe the injury patterns in adult swimmers and reported a high prevalence of shoulder, knee, and low back injuries due to overuse.[8] However, methodological differences in injury definitions, data collection, and injury surveillance limited the ability to draw direct comparisons between the studies. To our knowledge, there is no existing literature that describes the epidemiology of swimming and diving injuries specifically at the high school level.

It is critical that we evaluate data specific to the adolescent population, being that this group may be more susceptible to injury for many reasons. Rapid growth during adolescence may result in mechanical stress, such as muscle tightness across joints.[9] Training volume, a recognized risk factor for overuse injury, rapidly increases around this time for many swimmers; one study showed that training volumes among adolescent swimmers (ages 15–17) were greater than younger age groups.[9] Finally, there is growing concern that youth sport specialization amongst adolescents increases risk of musculoskeletal injury. Sport specialization, defined as participation in one sport at the exclusion of other sports, is associated with higher training volumes both in terms of hours per week and months per year, potentially with burnout and overtraining.[10,11]

Given the limited scope of available literature on swimming and diving injuries and the unique risk factors in the adolescent population, this study describes injury patterns across

high school swimmers and divers using data from a longitudinal national sports injury surveillance program, sampling a large number of US high schools. We specifically aim to: (1) calculate overall injury rates amongst high school swimmers and divers, (2) compare injury rates by gender and in practice versus competition, (3) examine general patterns in injury characteristics, and (4) attempt a subset analysis to examine differences in injury characteristics between swimmers and divers.

Methods

This study was approved by the MedStar Health Research Institutional Review Board (STUDY00003778).

Data Collection:

Data were obtained from the National High School Sports-Related Injury Surveillance System, High School Reporting Information Online (RIO). The methodology of this Internet-based surveillance system has been described previously[12,13,14] and replicated widely. Briefly, high schools with one or more National Athletic Trainers' Association (NATA)-certified athletic trainers (ATs) were eligible. Schools were categorized into 8 strata based on school enrollment (<1000 or >1000) and US Census geographic regions. Beginning in 2005, schools were randomly selected from each substratum to obtain 100 study schools reporting for the 9 sports included in the original sample (boys' football, soccer, basketball, wrestling, and baseball and girls' soccer, volleyball, basketball, and softball). Between 2008–2012, 13 sports were subsequently added, including boys' and girls' swimming and diving. If a school dropped out of the study, a replacement from the same stratum was randomly selected to maintain the 100-school study population. This sampling method produced a large national convenience sample of US high schools reporting injury data for boys' and girls' swimming and diving from 2008–2019 academic years.

Definition of Exposure and Injury:

Participating ATs logged onto the High School RIO website weekly throughout each academic year to report information on athlete exposures (AEs) and injuries. An AE was defined as 1 athlete participating in 1 school-sanctioned swimming and diving practice or competition. A reportable injury was defined as one that: (1) occurred as a result of participation in swimming and diving practice or competition; (2) required medical attention from an AT or physician; and, (3) restricted the athlete's participation in swimming and diving for at least 1 day OR resulted in any fracture, concussion, dental injury, or heat illness/injury regardless of whether it restricted participation. For each reported injury, ATs completed detailed injury reports including demographics (i.e. age, gender, year in school), injury information (i.e. anatomic location, type of injury, severity), and injury details (i.e. specific activity or event, mechanism of injury).

With each injury, ATs were asked, "In your professional opinion, do you believe the athlete returned to play before being fully recovered or before you would have released them to play?", with available responses being Yes/No/Unknown. ATs were not provided the

opportunity to detail underlying reasons for this opinion; given the method of data collection via centralized database, further detail on this variable was not obtainable. ATs were able to view and update reports as needed throughout the study period from 2008–2019 academic years.

Statistical Analysis:

Injury rates (IRs), rate ratios (RRs), and injury proportion ratios (IPRs) were calculated using injury case counts and AE data from the High School RIO convenience sample dataset, with associated 95% confidence intervals. These were calculated for the overall dataset and also stratified by competition vs. practice and gender. Injury rate trends over time were summarized. Descriptive analysis was also conducted to summarize the distribution of injuries by demographic characteristics (i.e. gender, year in school), anatomic location (i.e. shoulder, knee), and mechanism of injury (i.e. overuse, contact with board). Differences in injury distribution were evaluated using Fisher's exact test or chi-squared test. Data analysis was conducted using Stata17.0 software (Stata Corp, College Station, Texas).

Notably, swimming and diving is considered to be one sport and, therefore, these injuries are recorded in the High School RIO database together. Given that swimmers and divers have different biomechanical risk factors for injury, a subset analysis to identify injuries within swimmers and divers separately was also performed using specific inclusion and exclusion criteria (Figure 1), which have been described previously to determine athlete status in the collegiate swimming and diving population.[3] Inclusion criteria included those injuries listed with a recorded associated swimming-specific event (i.e. 50 freestyle, 100 freestyle etc.) and a clear indication that the athlete was a swimmer. Exclusion criteria for this subset were those injuries that did not have an event listed (unknown or not recorded by the AT), or those injuries that were listed with a diving event (1M diving). The same subset analysis was also performed with inclusion and exclusion criteria flipped (i.e. amongst known divers only). The limitations of this are considered further in the discussion.

Results

Injury Rates:

Between 2008–2019, a total of 563 injuries occurred during 2,171,260 total AE (0.26 per 1000 athlete exposures, 95% CI 0.24–0.28) (Table 1). Among boys, 202 injuries occurred during 1,015,129 total AE (0.20 per 1000 AE). Among girls, 361 injuries occurred during 1,156,131 total AE (0.31 per 1000 AE). Injury rates were higher in practice versus competition, approaching statistical significance ($p = 0.051$) (Table 1). Girls had higher injury rates than boys overall (RR 1.57; 95% CI, 1.32–1.86, $p<0.05$), in practice (RR 1.53; 95% CI 1.27–1.85, $p<0.05$), and in competition (RR 1.81; 95% CI 1.15–2.84, $p<0.05$). There were also no significant trends in injury rates over time (Figure 2). There were no significant differences in the proportion of injuries amongst classes (freshmen 23.1%, sophomores 27.2%, juniors 26.6%, and seniors 23.1%). In dividing injuries into specific swimming versus diving injury groups for the aforementioned subset analyses, of the 563 total injuries, there were 356 injuries that were assigned to swimming or diving with 207 (37%) injuries unassigned. The unassigned injuries, those for which swimming versus

diving status was unknown, were not analyzed separately for this analysis; this is a limitation of this study discussed further below.

Injury Characteristics:

Overall: The most commonly injured body part in swimmers and divers was the shoulder (41.0%), followed by the head/face (16.2%) and the knee (7.3%) (Table 2). The most frequent types of injuries were muscle strain (22.9%), tendonitis (18.7%), and concussion (15.0%) (Table 3). The most common mechanism of injury was overuse/chronic (48.3%). Overall, swimmers and divers returned to play most commonly in 1–2 days (25.4%) followed closely by returning to play in 3–6 days (25.0%) (Table 4). Additionally, 9.2% of injured boys and girls swimmers and divers returned to play too soon as determined by ATs; the underlying reasons for this designation were not specified. Among all reported injuries, 4.3% required surgery. When considering gender, the shoulder remained the most commonly injured anatomic location in both boys (43.0%) and girls (39.9%). There was no significant difference between overuse injuries in boys (48.5%) and girls (48.2%).

Swimming Injuries: Among swimming injuries (N=315), the most commonly injured anatomic location was the shoulder (48.6%), followed by the knee (8.9%), head (8.9%), and lower back/lumbar-spine/pelvis (7.3%). The most common mechanism of injury was overuse/chronic (58.0%), and the most common injury type was muscle strain (28.9%). Among swimmers with injuries in this category, 24.0% reported swimming with an additional club swim team, but this was not statistically significant compared to those who did not report club team participation (p=0.64). Amongst swimming-specific events, injuries were most commonly associated with the freestyle events (67.3%), followed by the butterfly events (14.0%) (Figure 3). Most swimmers returned to play in 3–6 days (27.9%);11.4% of swimmers returned to play too soon as determined by ATs. 3.8% of swimmers underwent surgery.

Diving Injuries: Among boys' and girls' diving injuries (N=41), the most commonly injured body part was the head/face (36.6%), followed by the knee (12.2%), foot/toe (12.2%), and shoulder (9.8%). The most common mechanism of injury was contact with the diving board (68.3%), followed by acute no contact (12.2%) and overuse/chronic (9.8%). Injury to the head accounted for 47% of diving injuries in boys and 29% of diving injuries in girls. Notably, a larger proportion of injuries in girls were to the knee (16.7%) than in boys (5.9%). The most common diving-specific injury type was concussion (31.7%). Most divers returned to play in 10–21 days (24.3%); 7.3% of divers returned to play too soon as determined by ATs. No divers required surgery.

Discussion

To our knowledge, this is the first study to describe the epidemiology of injuries in US high school swimmers and divers using data captured by a large, longitudinal national surveillance system. These data build a strong foundation on which to build greater understanding of injuries in adolescent swimmers and divers, with a few particularly notable findings.

First, this study demonstrated a lower overall injury rate (0.26 per 1000 AE) when compared to NCAA swimmers and divers (1.87 per 1000 AE).[3] This may be due to less practice exposure at a lower level of competition. Additionally, females consistently had significantly higher injury rates per exposure than males in all categories (overall, practice, and competition). This supports existing research on college swimming and diving injuries that has found a higher overall injury rate in female compared to male collegiate swimmers and divers,[5,8] and suggests that females may be at a higher risk for injury relative to males in the adolescent population as well. In contrast to previous studies,[5,15] however, there was no significant difference in the proportion of overuse injuries in girls and boys.

The shoulder was the most commonly injured anatomic location, consistent with previous studies on collegiate swimmers and divers.[3,4,5,6] The proportion of shoulder injuries increased to an even greater degree in the swimmer-only subset (Table 2), as did the proportion of overuse injuries. Competitive swimmers perform 10 times the number of movements of other overhand athletes,[16] and may swim up to 9 miles per day at the elite level.[17] The biomechanics of frequent overhead motion involved in most swimming strokes also predispose swimmers to overuse-type shoulder injuries, often referred to as “swimmer’s shoulder”.[17] Injuries associated with freestyle and butterfly, two strokes that put the most overhead stress on the shoulder,[17,18] were also the most frequent in this population. Of note, it has been reported that swimmers aged 13–18 years believe mild to moderate shoulder pain should be tolerated to complete practice and many use pain medication to complete practice.[19] Such attitudes in adolescents are concerning and present important considerations for swim coaches and ATs in this age group. While our data do not directly examine the effects of sport specialization on injury prevalence, it is important that involved parties understand the potential risks of routine medication use during adolescence as well as the long-term consequences of “playing through” their overuse injuries.

Consistent with previous studies on college diving injuries,[3,5] injuries to the head (including concussion) were the most frequent injury type in high school divers. As contact with the board was also the most common mechanism of injury in this subset, it is implied that these reported concussions were associated with direct head impact with the board. In addition to head-on-board impact, concussions in divers have also been reported to occur with head impact from water entry.[20] Divers also more frequently took longer to return to play (10–21 days) than swimmers (3–6 days), which is supported by the large proportion of reported head injuries and aligns well with reported return-to-play windows for concussion.[21,22] In swimming on the other hand, absolute rest is rarely indicated for overuse type injuries as it often results in rapid deconditioning of the swimmer.[17] Other common diving injuries in our population were to the foot/toe, knee, and shoulder. In divers, it is believed that lower extremity injuries usually occur at the take-off phase of the dive or with dry-land training.[20] Increased training volume and poor technique can also increase the risk of developing chronic overuse injuries such as patellar and quadriceps tendinitis, patellofemoral pain syndrome, Achilles tendinitis, and tibialis posterior tendinitis.[23,24,25] Notably in our sample, a larger proportion of injuries in female divers were to the knee (16.7%) than in male divers (5.9%); this may be partially explained by anatomical and biomechanical factors which predispose young females to patellofemoral pain.[26]

There are several inherent limitations to our study design. One major limitation of our study is that the High School RIO database records injury information for both swimmers and divers together as one group, as they compete on the same team in United States high school leagues. As such, we were unable to definitively calculate injury rates (number of injuries per AE) for each individual sport. These are two entirely different sports with different numbers of athletes competing (generally far more swimmers than divers on a team) and different biomechanical risk factors for injury. To accommodate this limitation and best characterize injuries occurring from each sport, we performed a descriptive subset analysis using available event information to classify injuries as resulting either from swimming or diving as previously described. However, this event information was not always available, resulting in a large number of athletes excluded from the subset analysis.

Another limitation of this study is that many elite swimmers and divers in this age group train outside of the high school setting, while competing but not practicing with their high school teams.[27,28,29] This creates a source of potential selection bias as these athlete injuries may be missed more frequently in our sample that relies on the reporting of ATs employed by the high school. In a recent survey, 79% of female college swimmers reported having also trained on a club team while in high school.[28] Club swimming and club diving, as opposed to high school swimming and diving, are usually year-round and often involve more weekly hours devoted to training,[27,28,29] leading to further potential to develop an injury. Interestingly, there were no statistically significant increases in rates of injury among swimmers and divers who also participated in club swimming and diving. On one hand, this is surprising given the significantly increased exposure to their sport, potentially increasing the risk of overuse injury. However, one might consider the counterargument that many overuse injuries occur during periods when training volume and intensity change significantly[7], a circumstance which may occur less with year-round simmers. Regardless, this warrants further exploration in future studies, ideally with larger sample sizes which better characterize training volumes, as well as the change in training volumes over a sustained period of time.

This study reveals elevated injury rates among adolescent female swimmers and divers compared to their male counterparts, consistent with similar findings in the collegiate population. It also provides data demonstrating anatomic injury patterns among swimmers and divers separately; however, given the limitations of the subset analyses as discussed above, further studies are warranted to better characterize swimming and diving injuries in this vulnerable age group. Currently, there is no standardized injury-related education for USA Swimming coaches of athletes at this age.[30] Given the results of this study, high school swimming and diving coaches and ATs may consider sport-specific and gender-specific risk factors when working with their adolescent athletes to prevent injury. For example, coaches may consider adjusting training plans for female freestyle and butterfly swimmers to include a higher volume of shoulder injury prevention exercises out of the water. Likewise, diving coaches should keep in mind the increased risk of impact-related injuries, and work on developing strategies to mitigate this when teaching the mechanics of specific dives. In summary, further research in gender specific injury prevention is needed to develop stronger evidence-based, targeted injury prevention programs in high school swimming and diving.

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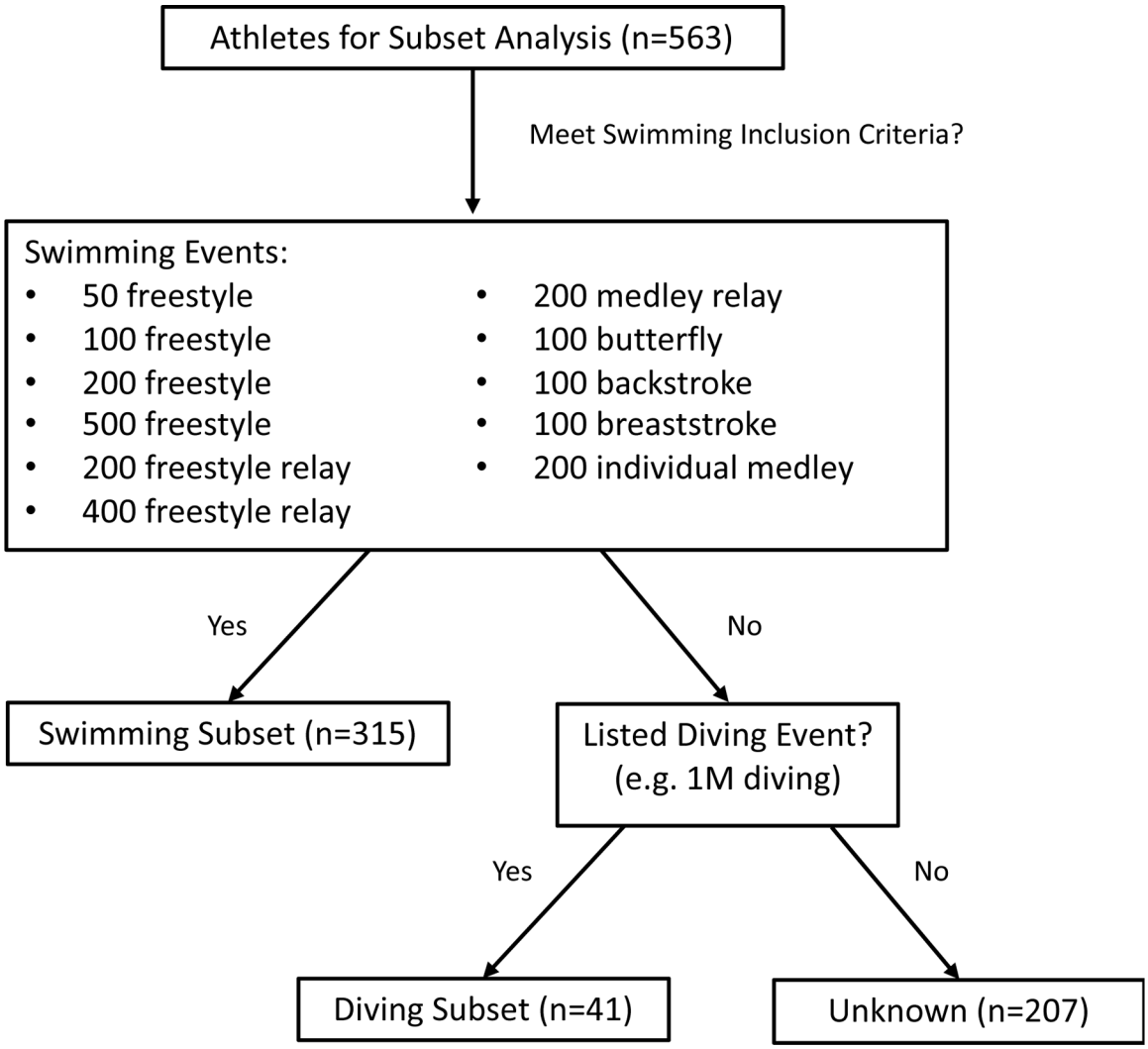

Figure 1:
Subset Analysis Flowchart

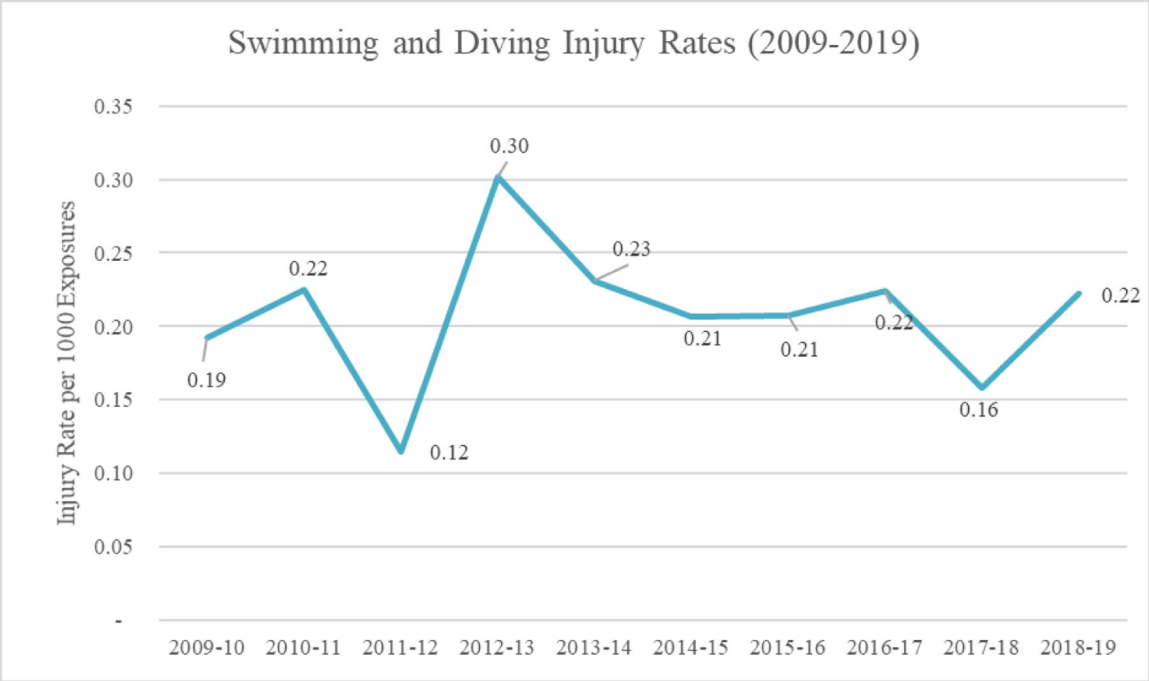

Figure 2:
Overall Swimming and Diving Injury Rates from 2009– 2019

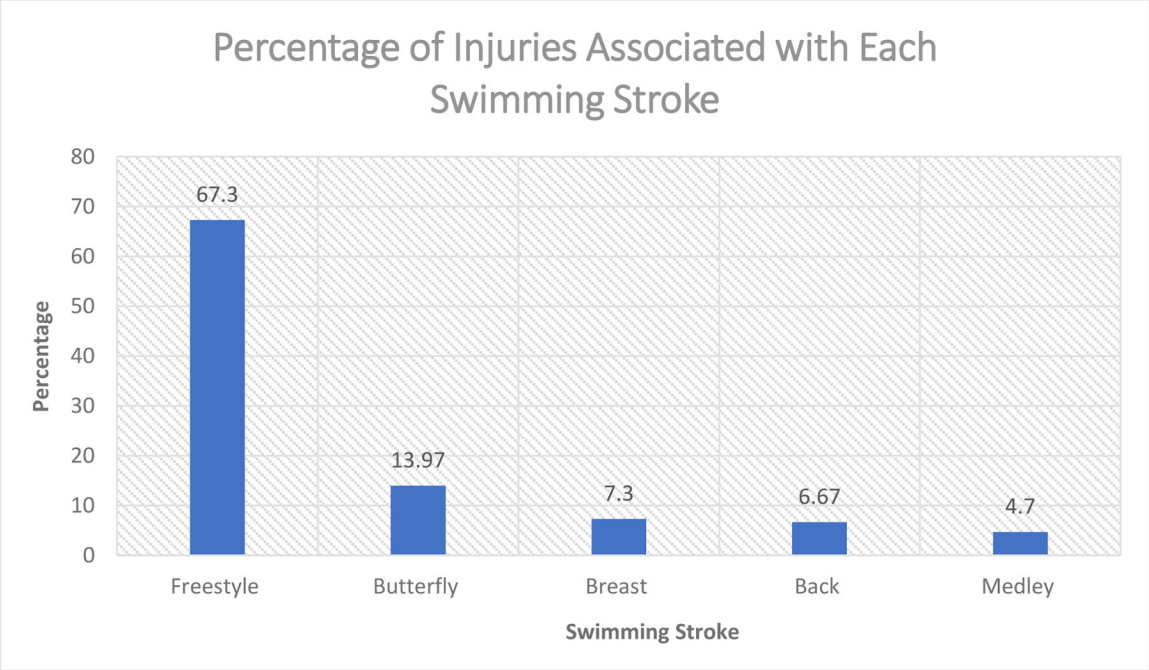

Figure 3:
Percentage of Injuries Associated with Each Swimming Stroke

Table 1:

Incidences and Rates of Swimming and Diving Injuries per 1000 AEs by Type of Exposure[a]

Sport	No. of Injuries	No. of AEs	Rate/1000 AEs	Rate Ratio[b]	Rate Ratio[c]	95% CI
Boys						
Total	202	1,015,129	0.20			
Competition	28	187,302	0.15			
Practice	174	827,827	0.21			
				0.71		0.48–1.06
Girls						
Total	361	1,156,131	0.31			
Competition	59	218,040	0.27			
Practice	302	938,091	0.32			
				0.84		0.64–1.11
Overall						
Total	563	2,171,260	0.26		1.57[d]	1.13–1.86[d]
Competition	87	405,342	0.21		1.81[d]	1.15–2.84
Practice	476	1,765,918	0.27		1.53[d]	1.27–1.85 [d]
				0.80	0.80	0.63–1.00

[a] AE, athlete exposure.

[b] Comparison of competition versus practice rates

[c] Comparison of girls to boys

[d] Significant at a level of $p<0.05$

Table 2:

Injuries by Anatomic Location in the Overall, Swimming, and Diving Groups

Injuries	n (%)
Overall	
Shoulder	231 (41.0)
Head/face	91 (16.2)
Knee	41 (7.3)
Lower leg strain	50 (4.3)
Knee tendinitis	40 (3.4)
Lower leg shin splints	38 (3.3)
Lower leg other	29 (2.5)
Lower back/L-spine/pelvis	28 (2.4)
Swimming	
Shoulder	153 (48.6)
Head/face	28 (8.9)
Knee	28 (8.9)
Lower back/L-spine/pelvis	23 (7.3)
Chest/T-spine/ribs	11 (3.5)
Thigh/upper leg	11 (3.5)
Foot/toe	10 (3.2)
Elbow	8 (2.5)
Diving	
Head/face	15 (36.6)
Knee	5 (12.2)
Foot/toe	5 (12.2)
Nose	4 (9.8)
Wrist	2 (4.9)
Chest/T-spine/ribs	2 (4.9)
Lower leg	2 (4.9)
Ear(s)	1 (2.4)

Table 3:

Injury Types in the Overall, Swimming, and Diving Groups

Types of Injuries	n (%)
Overall	
Muscle strain	128 (22.9)
Tendonitis	105 (18.7)
Concussion	84 (15.0)
Other	53 (9.5)
Ligament sprain	26 (4.7)
Swimming	
Muscle strain	91 (28.9)
Tendonitis	64 (20.3)
Other	30 (10.2)
Concussion	26 (8.3)
Muscle strain (incomplete tear)	16 (5.1)
Diving	
Concussion	13 (31.7)
Muscle strain	6 (14.6)
Contusion	4 (9.8)
Laceration	4 (9.8)
Subluxation	4 (9.8)

Table 4:

Return to Play Outcomes in the Overall, Swimming, and Diving Groups

Outcomes	n (%)
Overall	
1–2 days	137 (25.4)
3–6 days	135 (25.1)
10–21 days	97 (18.0)
7–9 days	88 (16.3)
Season ended before athlete returned to activity	32 (6.0)
Swimming	
3–6 days	85 (27.9)
1–2 days	81 (26.6)
7–9 days	54 (17.7)
10–21 days	47 (15.4)
Season ended before athlete returned do activity	16 (5.3)
Diving	
10–21 days	9 (24.3)
1–2 days	8 (21.6)
3–6 days	7 (19.0)
7–9 days	4 (10.8)
10–21 days	3 (8.1)