Preseason Aerobic Fitness Predicts In-Season Injury and Illness in Female Youth Athletes

Andrew Watson,*† MD, MS, Stacey Brickson,† PhD, M. Alison Brooks,† MD, MPH, and Warren Dunn,† MD, MPH

Investigation performed at University of Wisconsin Health Research Park, Madison, Wisconsin, USA

Background: Although preseason aerobic fitness has been suggested as a modifiable risk factor for injury in adult athletes, the relationship between aerobic fitness, injury, and illness in youth athletes is unknown.

Purpose: To determine whether preseason aerobic fitness predicts in-season injury and illness risk in female adolescent soccer players.

Study Design: Case-control study; Level of evidence, 3.

Methods: Fifty-four female adolescent soccer players underwent preseason evaluation to determine years of experience, body mass index (BMI), maximal aerobic capacity (VO_{2max}), and time to exhaustion (T_{max}) during cycle ergometer testing. All injuries and illnesses during the subsequent 20-week season were recorded. Variables were compared between individuals with and without a self-reported injury and individuals with and without a self-reported illness. Separate Poisson regression models were developed to predict number of injuries and illnesses for each individual by use of age, years of experience, BMI, VO_{2max}, and T_{max}.

Results: Twenty-eight injuries and 38 illnesses in 23 individuals were recorded during the season. Although not a statistically significant finding, individuals who reported an in-season injury had lower VO_{2max} than those who did not (54.9 ± 7.3 vs 58.3 ± 8.5 mL/kg/min, $P = .13$). Individuals who reported an illness had significantly lower VO_{2max} than those who did not (54.5 ± 9.9 vs 58.8 ± 6.2 mL/kg/min, $P = .014$). With the Poisson regression models, VO_{2max} was a significant predictor of both injury (odds ratio [OR], 0.95; $P = .046$) and illness (OR, 0.94; $P = .009$), while no significant relationships were identified between injury or illness and age, years of experience, T_{max}, or BMI (all $P > .05$).

Conclusion: Among adolescent female soccer players, greater preseason aerobic fitness is associated with a reduced risk of in-season injury and illness. Off-season intervention to promote aerobic fitness may help reduce the risk of lost time during the season due to injury and illness.

Keywords: VO_{2max}; aerobic capacity; soccer; adolescent

Although the benefits of exercise are considerable, sport participation is associated with an increased risk of injury.[18,21] Soccer has been identified as the high school sport with the greatest risk of injury for female athletes,[6] with injury rates between 2 and 4 injuries per 1000 hours when reported by medical staff[2,8,29,35] and as high as 15.3 per 1000 hours when identified through self-reported mechanisms.[5] Recent research in adult athletes has suggested that time losses due to injury and illness are major determinants of athletic success.[31] Consequently, the identification of modifiable risk factors in youth athletes that can be quantified and modified before or during the athletic season can potentially reduce in-season injury in athletes.

Prior research in a variety of adult populations has suggested that aerobic fitness may be a modifiable risk factor for injury.[3,4,22-24,28] Multiple prior studies have demonstrated a strong association between higher levels of aerobic fitness and decreased risk of injury among firefighters and during military training.[23-25,28,32] Although a recent

*Address correspondence to Andrew Watson, MD, MS, Department of Orthopedics and Rehabilitation, Division of Sports Medicine, 1685 Highland Avenue, Madison, WI 53705, USA (email: Watson@ortho.wisc.edu).

†Department of Orthopedics, University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin, USA.

The authors declared that they have no conflicts of interest in the authorship and publication of this contribution.

Ethical approval for this study was obtained from the University of Wisconsin Health Sciences IRB (submission No. 2014-0373).

The Orthopaedic Journal of Sports Medicine, 5(9), 2325967117726976
DOI: 10.1177/2325967117726976

study of male collegiate hockey players found that aerobic fitness was not a predictor of in-season injury,[16] a separate study of Australian football players found that low aerobic fitness was associated with increased risk of injury.[14] In these studies, however, fitness was determined indirectly through a 6-minute run[14] or 1-, 1.5-, and 5-mile runs,[16] which may be influenced by additional factors such as anaerobic power and motivation. It was recently found that higher preseason fitness was associated with a decreased risk of in-season injury among male and female collegiate soccer players when measured directly as maximal aerobic capacity (VO_{2max}).[34] Together, these findings suggest that off-season interventions in adult athletes to improve aerobic fitness may reduce in-season injury risk.

Research in adult military and athletic populations has also suggested that higher levels of aerobic fitness may be protective against illness. Among male army recruits, lower initial aerobic fitness was associated with a longer duration of symptoms from upper respiratory tract infections during basic training.[7] Although we are not aware of research directly evaluating the influence of preseason fitness on illness risk in adult athletes, increased incidence of illness has been associated with increased training loads in multiple sports.[9,15,19,33] Individuals with lower levels of fitness may be predisposed to higher fatigue with comparable workloads,[4,13] potentially increasing their susceptibility to infection.

Research regarding the influence of preseason fitness on in-season injury and illness risk in youth athletes is minimal and conflicting. While preseason aerobic fitness determined indirectly from shuttle run tests was associated with in-season injury risk among adolescent male Australian football players,[4] no such relationship was found for adolescent male soccer players.[11] No prior research has evaluated this relationship in female youth athletes. Similarly, while higher levels of aerobic fitness have been associated with decreased hospitalization rates among children with cystic fibrosis, we are aware of no studies that have evaluated this relationship in youth athletes. Therefore, the purpose of this study was to determine whether preseason aerobic fitness predicts in-season injury and illness risk in female adolescent soccer players.

METHODS

Study Design

All procedures performed in this study were approved by the Institutional Review Board of the University of Wisconsin–Madison. Female athletes ages 13 to 18 years were recruited through their participation in a local youth soccer organization. Interested participants were asked to provide information regarding any medications or significant cardiac or pulmonary disease that could affect cardiovascular function or performance (eg, stimulants, congenital cardiac disease, uncontrolled hypertension, uncontrolled asthma). Eligible minor participants were asked to provide informed assent, while adult participants and parents of minor participants provided informed consent.

Eligible participants underwent physiological testing immediately prior to the start of a 20-week soccer season. Although all participants compete in soccer year-round, the 20-week soccer season represents the primary club season during which all of their formal league competition takes place. After participants provided information regarding their age and years of soccer experience, height was measured with a stadiometer to the nearest 0.25 cm and body mass with a calibrated balance beam scale to the nearest 0.1 kg. Each participant then underwent a progressive, maximal exercise test on an electronically braked cycle ergometer (Velotron; Racermate). Participants were familiarized with the exercise testing equipment, after which they were asked to pedal in an upright position at a cadence of 70 rpm with an initial load of 85 W and incremental loads of 35 W applied at 3-minute intervals to the point of exhaustion, defined as the point when the pedal cadence could no longer be maintained despite strong verbal encouragement. During the test, total ventilation, oxygen consumption (VO_2), and carbon dioxide production (VCO_2) were measured in a continuous, breath-by-breath manner by a metabolic cart (Cosmed), and respiratory exchange ratio was calculated (ie, VCO_2/VO_2). To account for variations in breath-by-breath measurement, these values were expressed as a 30-second rolling average. VO_{2max} was defined as the highest value obtained during the test and was recorded along with time to exhaustion (T_{max}). Ventilatory threshold (VT) was determined as the point at which an upward deflection was noted in the slope of total ventilation over time, and both time to VT (T_{VT}) and oxygen consumption at VT (VO_{2VT}) were recorded. VO_{2max} and both in absolute terms expressed absolutely (L/min) and relative to body mass (mL/kg/min). A test was considered maximal if the athlete satisfied at least 2 of the following 3 objective criteria: (1) maximal heart rate more than 90% of the predicted maximal heart rate; (2) respiratory exchange ratio higher than 1.1; (3) a plateau in oxygen consumption, defined as a change of less than 2 mL/kg/min in oxygen consumption over the last 60 seconds of the test. All of the fitness testing was conducted by a primary care sports medicine physician with several years of prior testing experience.

Immediately following all soccer-related physical activity during this study season, including games, team training, and individual training, participants used an online software program (fitfor90.com) to provide the duration (expressed in minutes) and intensity (scored from 1 to 10) of their activity. These values were used to calculate a rating of perceived exertion per session as a measure of internal training load.[9,10] Throughout the season, injuries and illnesses were self-reported by the participants using the same computer software. In accordance with a consensus statement definition of time-loss injury in soccer,[12] participants were asked to report any injury that occurred during a soccer training or game and resulted in the athlete's being unable to continue to participate. They were asked to provide the date of the injury (if not reported on the same day it occurred), the body part involved, and the mechanism (if known). Acute injuries were defined as those with a sudden onset during an identifiable event, while overuse was

defined as having a gradual onset and being unrelated to a specific event. Both first-time and repeat injuries were included if they were believed to represent new injuries based on resolution of symptoms and return to full participation between injuries. Participants were similarly asked to report any illnesses that resulted in restriction from participation in soccer events, including the date of onset and predominant symptoms. Follow-up interviews were conducted by the primary investigator (A.W.) via telephone or in person in any instances in which the details of the injury or illness were unclear. The coaching staff encouraged participants to report all injuries and illnesses resulting in lost time throughout the season.

Statistical Analysis

Data were initially evaluated for normality by use of descriptive statistics and histogram analysis. Injuries and illnesses were grouped by week of the season and were presented descriptively. Individuals were initially grouped based on whether they had an injury (injury, no injury) or illness (illness, no illness) during the season. Variables were compared between groups by use of Wilcoxon rank sum tests for means and chi-square or Fisher exact tests for frequencies, as appropriate. Participants were then grouped by number of injuries (0, 1, $\geq$2) or illnesses (0, 1, $\geq$2) reported during the season, and relative VO_{2max} was compared between groups by use of Kruskal-Wallis test with post hoc pairwise Wilcoxon tests. Adjustments were made for multiple pairwise comparisons,[20] and effect sizes were calculated using the Cohen *d*.

Because the numbers of injuries and illnesses were not sufficient to support a large number of predictors in multivariable regression models, separate univariable Poisson regression models were initially developed to predict the number of in-season injuries and illnesses for each participant through use of VO_{2max}, T_{max}, age, years of experience, and body mass index (BMI) as predictors. Because VO_{2max}, BMI, and years of experience all had a significance level $\leq$.10 in the univariable analysis to predict in-season illness, these 3 covariates were included in a multivariable Poisson regression model to predict the number of individual in-season illnesses. Significance level was determined a priori at the .05 level, and all tests were 2-tailed. All statistical analyses were performed in R.[30]

In our prior research in collegiate soccer athletes,[34] we found a mean VO_{2max} difference between injured and uninjured players of 5.7 mL/kg/min and a pooled standard deviation of 7.15, yielding a large effect size of 0.80. While we are aware of no similar research with respect to illness, we based our sample size calculations for illness on a similar effect size. Assuming a significance level of .05, we would need at least 6 individuals per injury or illness group to identify a difference in VO_{2max} with a power of 0.8 (18 total participants for 3 groups). For our Poisson regression models using individual preseason variables such as VO_{2max} to predict the in-season number of injuries or illnesses, it is generally considered acceptable to have at least 10 to 15 outcomes per predictor variable within the model. Considering our prior research in collegiate soccer athletes, we could expect that at least half of our sample would suffer an injury or illness during the season. As such, a sample size of 30 would likely result in at least 15 injuries and illnesses to sufficiently power each univariable Poisson or logistic regression.

TABLE 1
In-Season Injury Characteristics Among Adolescent Female Soccer Players

	n (%)
Total injuries	28
Injury location	
Ankle	12 (43)
Knee	5 (18)
Head	5 (18)
Upper leg	3 (11)
Back	2 (7)
Foot	1 (4)
Injury type	
Sprain	18 (65)
Muscle strain	3 (11)
Concussion	4 (14)
Contusion	2 (7)

RESULTS

Fifty-four participants satisfied the criteria for inclusion. Overall, 28 injuries were identified in 23 participants, while 38 illnesses were recorded in 23 participants. Five participants had 2 injuries. Six participants had 2 illnesses, 3 participants had 3 illnesses, and 1 participant had 4 illnesses during the season. This yielded an overall incidence rate of 5.3 injuries per 1000 hours and 9.2 illnesses per 1000 hours. Ankle and knee were the most commonly injured body part, while sprains were the most commonly reported injury type (Table 1).

Illnesses consisted of 25 (66%) respiratory infections, 7 (18%) gastrointestinal infections, 2 (5%) isolated fevers, 2 (5%) episodes of acute otitis media, 1 (3%) episode of conjunctivitis, and 1 (3%) episode of body aches. Whereas injuries seemed to be somewhat more likely in the first few weeks of the season, illnesses appeared to be slightly more common toward the middle of the season (Figure 1).

Although not a statistically significant finding, individuals who reported an in-season injury had lower VO_{2max} than those who did not report an in-season injury (54.9 $\pm$ 7.3 vs 58.3 $\pm$ 8.5 mL/kg/min, respectively; $P = .13$) (Table 2). Individuals who reported an illness had significantly lower VO_{2max} than those who did not report an illness (54.5 $\pm$ 9.9 vs 58.8 $\pm$ 6.2 mL/kg/min, respectively; $P = .014$) (Table 3). In addition, preseason VO_{2max} was lower among those participants with higher numbers of in-season injuries and illnesses (Figures 2 and 3, respectively).

The Poisson regression analysis revealed that preseason VO_{2max} was a significant predictor of the number of injuries (odds ratio [OR] = 0.95; 95% confidence interval [CI], 0.90-0.99; $P = .046$) and illnesses (OR = 0.94; 95% CI, 0.90-0.98; $P = .009$) sustained during the season, while no significant

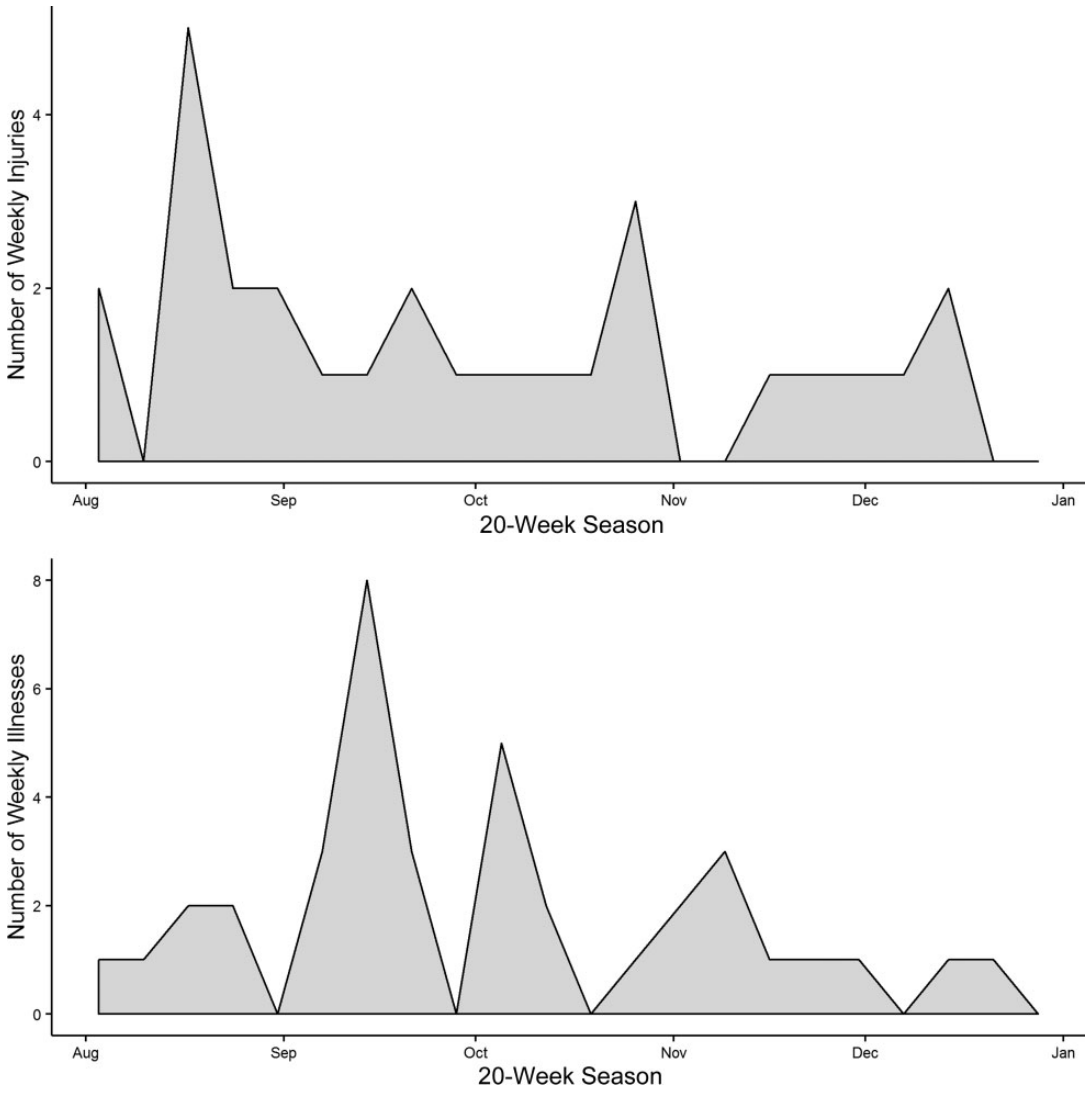

Figure 1. Number of weekly injuries and illnesses among adolescent female soccer players during a 20-week season.

TABLE 2
Differences in Preseason Variables Between Adolescent Female Soccer Players Who Sustained an Injury During the Season and Those Who Did Not[a]

	Uninjured (n = 31)[b]	Injured (n = 23)[b]	*P*	Cohen *d*
Age, y	15.1 ± 1.5	15.7 ± 1.5	.15	–0.41
Body mass index	20.9 ± 2.7	21.2 ± 2.1	.46	–0.09
Soccer experience, y	9.06 ± 2.6	9.09 ± 3.7	.70	–0.008
VO_{2max}, L/min	3.28 ± 0.54	3.15 ± 0.56	.30	0.23
VO_{2max}, mL/kg/min	58.3 ± 8.5	54.9 ± 7.3	.13	0.43
T_{max}, min	14.9 ± 2.1	14.4 ± 2.0	.48	0.24
VO_{2VT}, L/min	2.72 ± 0.43	2.59 ± 0.50	.16	0.27
VO_{2VT}, mL/kg/min	48.4 ± 7.7	45.3 ± 7.6	.17	0.41
T_{VT}, min	11.4 ± 1.7	11.3 ± 1.3	.80	0.07

[a]Comparisons made by Wilcoxon rank sum and chi-square tests for continuous and categorical variables, respectively. T_{max}, time to exhaustion; T_{VT}, time to ventilatory threshold; VO_{2max}, maximal aerobic capacity; VO_{2VT}, ventilatory threshold.
[b]Data presented as mean ± SD.

TABLE 3
Differences in Preseason Variables Between Adolescent Female Soccer Players Who Reported an Illness During the Season and Those Who Did Not[a]

	No Illness (n = 31)[b]	Illness (n = 23)[b]	*P*	Cohen *d*
Age, y	15.3 ± 1.6	15.4 ± 1.5	.88	–0.034
Body mass index	21.0 ± 1.9	21.1 ± 3.1	.62	–0.07
Soccer experience, y	9.0 ± 2.7	9.2 ± 2.5	.77	–0.09
VO_{2max}, L/min	3.32 ± 0.49	3.10 ± 0.60	.29	0.41
VO_{2max}, mL/kg/min	**58.6 ± 6.2**	**54.6 ± 9.8**	**.020**	**0.50**
T_{max}, min	15.0 ± 1.5	14.3 ± 2.5	.46	0.24
VO_{2VT}, L/min	2.73 ± 0.46	2.57 ± 0.46	.35	0.40
VO_{2VT}, mL/kg/min	48.2 ± 6.6	45.6 ± 9.1	.059	0.43
T_{VT}, min	11.5 ± 1.3	11.0 ± 1.8	.20	0.27

[a]Comparisons made by Wilcoxon rank sum and chi-square tests for continuous and categorical variables, respectively. Bolded values indicate statistical significance. T_{max}, time to exhaustion; T_{VT}, time to ventilatory threshold; VO_{2max}, maximal aerobic capacity; VO_{2VT}, ventilatory threshold.
[b]Data presented as mean ± SD.

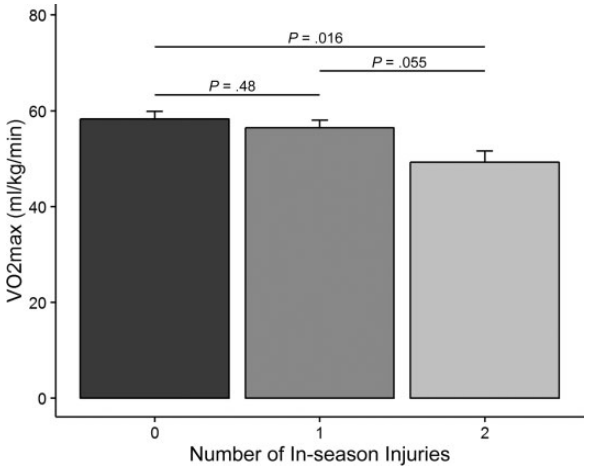

Figure 2. Comparison of preseason maximal aerobic capacity (VO_{2max}) among adolescent female soccer athletes by number of injuries sustained during the season. Data represent mean and standard error.

relationships were identified between injury or illness and age, years of experience, or BMI (Tables 4 and 5).

DISCUSSION

Among adolescent female soccer players, higher levels of preseason fitness were predictive of decreased in-season injury. Preseason aerobic fitness was a significant predictor of the number of in-season injuries for an individual, with a roughly 5% decrease in injury risk for every 1-mL/kg/min increase in preseason VO_{2max}. These findings are in agreement with prior research in the military and in adult athletes,[14,22,23,25] and it has been suggested that the physiological and biomechanical adaptations that accompany aerobic fitness may be protective against injury, particularly with the onset of fatigue in the later portions of

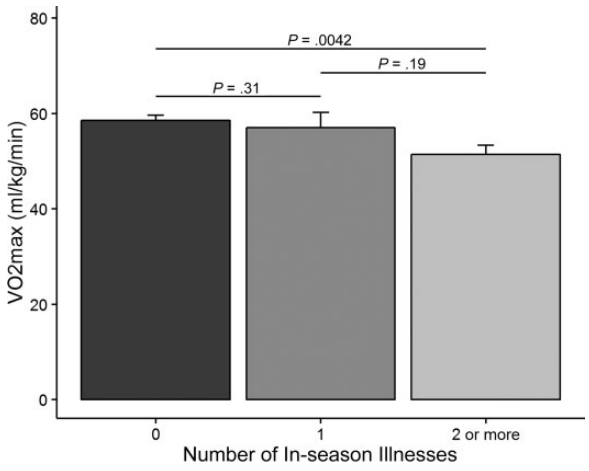

Figure 3. Comparison of preseason maximal aerobic capacity among adolescent female soccer athletes by number of illnesses sustained during the season. Data represent mean and standard error.

TABLE 4
Univariable Poisson Regression Analysis to Identify Predictors of In-Season Injury in Adolescent Female Soccer Players[a]

	Odds Ratio (95% CI)	*P*
Age, y	1.07 (0.84-1.38)	.59
Body mass index	1.02 (0.87-1.19)	.80
Soccer experience, y	0.94 (0.83-1.09)	.42
VO_{2max}, mL/kg/min	**0.95 (0.90-0.99)**	**.046**
T_{max}, min	0.89 (0.75-1.06)	.18

[a]Bolded values indicate statistical significance. CI, confidence interval; T_{max}, time to exhaustion; VO_{2max}, maximal aerobic capacity.

TABLE 5
Univariable and Multivariable Poisson Regression Analyses to Identify Predictors of In-Season Illness in Adolescent Female Soccer Players[a]

	Univariable Analysis		Multivariable Analysis	
	Odds Ratio (95% CI)	*P*	Odds Ratio (95% CI)	*P*
Age, y	1.17 (0.95-1.46)	.15		
Body mass index	1.11 (0.98-1.27)	*.090*	1.04 (0.91-1.20)	.57
Soccer experience, y	1.12 (0.98-1.28)	*.10*	1.09 (0.95-1.27)	.24
VO_{2max}, mL/kg/min	**0.94 (0.90-0.98)**	**.005**	**0.94 (0.90-0.98)**	**.009**
T_{max}, min	1.02 (0.87-1.21)	.79		

[a]Bolded values indicate statistical significance. CI, confidence interval; T_{max}, time to exhaustion; VO_{2max}, maximal aerobic capacity.

events.[26] Research has previously shown that preseason VO_{2max} was a significant predictor of in-season injury in collegiate soccer players, independent of body composition and sex.[34] The current study suggests that higher levels of preseason aerobic fitness are similarly associated with decreased risk of injury in adolescent female athletes.

Findings with respect to illness and fitness were very similar. Aerobic fitness was greater in individuals who did not experience any illnesses during the season, and preseason VO_{2max} was a significant predictor of the number of in-season illnesses experienced by an individual. An increase of 1 mL/kg/min of VO_{2max} was associated with an approximately 6% decrease in illness during the season, similar to the findings regarding injury. Although it has been suggested that strenuous exercise may be immunosuppressive, minimal research exists regarding the relationship between fitness and illness risk in athletes.[7] It is conceivable that higher levels of fitness may be protective against the immunosuppressive effects of high in-season training loads, but the specific mechanism responsible for this relationship cannot be evaluated in the current study. Nonetheless, our findings suggest that increased aerobic fitness at the start of the season may reduce the risk of in-season illness in youth athletes.

We failed to identify a relationship between in-season injury risk and any other risk factors among this population of soccer players, including age, BMI, or playing experience. Although considerable research has attempted to identify the relationship between body composition and injury, the findings have been conflicting.[1,14,16,17,24,27] Whereas BMI is often used as an indirect measure of adiposity in the general public, the significant influence of muscle mass on BMI in high-level athletes may confound this relationship. Although a prior study of middle school and high school athletes from multiple sports found that injury risk increased with age, Watson et al[34] found that age was unrelated to in-season injury risk in a group of collegiate soccer athletes. We are aware of no prior research that has evaluated years of experience as a risk factor for injury in female youth athletes. Although the relationships between in-season illness and increased BMI and age approached significance in the univariable regression analysis, these relationships were not meaningful after inclusion in the multivariable model. This result suggests that BMI and age are not independent predictors of in-season illness in adolescent female soccer players after accounting for the influence of aerobic fitness level. We also found no relationship between years of experience and in-season illness, and we are aware of no prior studies that have evaluated this relationship.

Together, these results suggest that the physiological adaptations that accompany higher levels of aerobic fitness offer protection against in-season injury and illness. Recent research suggests that in addition to the health burden of injuries and illnesses themselves, time lost to in-season injuries and illnesses is a major determinant of athletic success and the ability of individual athletes to reach their personal goals.[31] This association suggests that efforts to identify and address low levels of aerobic fitness during the off-season not only may improve overall health among youth athletes but also may contribute to athletic success. Further research is warranted to evaluate the effects of off-season intervention to increase aerobic fitness on subsequent injury and illness risk.

This study has several limitations. Although self-reported injuries resulting in time loss have been used in prior similar research,[5] we did not confirm the specific diagnoses of reported injuries and illnesses, and it is possible that not all injuries or illnesses were reported during the study period. We also did not quantify the duration of the injury or illness prior to return to play and cannot comment on injury or illness severity. While we included a number of potential additional risk factors, it is possible that variables we failed to include, such as strength, agility, or sport specialization, could exert a confounding influence on the relationship between preseason fitness and in-season injury and illness. This study included only adolescent female soccer players and may not be generalizable to other populations.

In conclusion, we found that preseason aerobic fitness level, expressed as relative VO_{2max} (mL/kg/min), was a significant predictor of in-season injury and illness among female adolescent soccer players. Specifically, those individuals without in-season injuries or illnesses had significantly higher preseason VO_{2max} than did those who had multiple injuries or illnesses during the season, and an increase of 1 mL/kg/min of preseason VO_{2max} was associated with 5% and 6% decreases in in-season injury and illness risk, respectively.

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