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Sport Specialization in Middle School and High School Long-Distance Runners

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Context: Previous reports suggested that highly specialized adolescent athletes may be at a higher risk of injury, worse sleep quality, and less sport enjoyment than low-level specialized athletes. To date, the sport specialization literature has primarily addressed adolescent athletes in a variety of sports. However, whether the findings on sport specialization in predominantly nonrunning athletes are generalizable to adolescent long-distance runners is unknown.

Objective: To compare injury history, running volume, quality of life, sleep habits, and running enjoyment among male and female middle school and high school long-distance runners at different sport specialization levels.

Design: Cross-sectional study.

Setting: Online survey.

Patients or Other Participants: A total of 102 male (age = 15.8 ± 0.9 years) and 156 female (age = 15.6 ± 1.4 years) uninjured middle school and high school athletes who participated in long-distance running activities (completion rate = 50.7%).

Main Outcome Measure(s): Participants were stratified by sex and sport specialization level (low, moderate, or high). Group differences were assessed in self-reported running-related injuries, running habits, EQ-5D-Y quality of life, Pittsburgh Sleep Quality Index sleep quality, sleep duration, and running enjoyment.

Results: Highly specialized male and female middle school and high school long-distance runners reported more months of competition per year ($P < .001$), higher weekly run distance ($P < .001$), more runs per week ($P < .001$), higher average distance per run ($P < .001$), and greater running enjoyment ($P < .001$) than low-level specialized runners. Adolescent boys reported a higher average weekly run distance ($P = .01$), higher average distance per run ($P = .01$), and better sleep quality ($P = .01$) than adolescent girls. No differences among sport specialization levels were found for running-related injuries ($P = .25$), quality of life ($P = .07$), sleep quality ($P = .19$), or sleep duration ($P = .11$) among male or female middle school and high school runners.

Conclusions: Highly specialized male and female middle school and high school long-distance runners reported higher running volumes and running enjoyment than low-level specialized runners. However, high-level specialized runners did not describe a greater number of running-related injuries, lower quality of life, or lower sleep quality or duration as expected.

Key Words: adolescent athletes, quality of life, sleep, running-related injury

Key Points

- Highly specialized male and female middle school and high school long-distance runners reported higher running volumes than low-level specialized long-distance runners.
- Running-related injuries, quality of life, and sleep quality and duration were not different among sport specialization levels for male or female middle school and high school long-distance runners.

Approximately 8 million adolescents participate in US high school athletics.[1] Long-distance running is a popular individual sport among adolescent athletes: nearly 500 000 high schoolers participated in cross-country in a recent academic year.[1] Although running provides a variety of physical and mental health benefits, adolescent runners demonstrate a high risk of sustaining a running-related injury (RRI). Upward of 68% of high school runners reported a history of RRI,[2] and 1 of every 3 sustained an RRI during a cross-country season.[3]

During adolescence, athletes may choose to focus their training on a single sport.[4] *Sport specialization*, often defined[5] as "year-round intensive training in a single sport at the exclusion of other sports," has become more common in adolescent athletics.[6,7] Recent authors[8–11] found that 26.0% to 37.5% of adolescent athletes were classified as highly specialized. Sport specialization may negatively affect quality of life (QoL) in adolescent athletes[12,13] and increase the risk of sustaining an injury.[4–6,10,11,14–17]

Athletes who are more specialized in a sport may also have less sleep quality and sport enjoyment. For instance, specialized adolescent female soccer athletes reported lower levels of wellbeing and sleep quality than their non-specialized counterparts.[13] Also, elite gymnasts who specialized earlier in life indicated they had less fun and lower QoL than nonelite gymnasts.[12] These findings of lower QoL were not universal, because similar levels of health-related QoL were present in high school athletes across specialization levels in other sports[8]; however, cross-country athletes represented only 5.2% of participants (n = 5).

Most previous researchers[4,8,10,11,14–16] who examined differences in sport specialization levels included athletes from a wide range of sports, and the effect of sport specialization on adolescent athletes may be influenced by sport type. Adolescent athletes who participated in individual sports were more likely than athletes who specialized in team sports to specialize in their sport, report higher training volumes, and have an increased injury risk.[4,18] Therefore, sport-specific investigations are warranted to determine whether current sport specialization guidelines may be generalized to adolescent athletes in specific sports.

Among 126 high school female cross-country runners, highly specialized female runners were 75% more likely than low-level specialized runners to sustain an RRI, and they experienced a greater frequency of major RRIs during the course of a season.[17] Because this investigation was limited to adolescent girls, it is unclear whether the relationships would be similar for male adolescent long-distance runners. Furthermore, to our knowledge, no authors have assessed the differences in QoL, sleep habits, or running enjoyment among middle school and high school long-distance runners at different sport specialization levels. Thus, the purpose of our study was to examine injury history, running volume, QoL, sleep habits, and running enjoyment among middle school and high school male and female long-distance runners at different sport specialization levels. We hypothesized that highly specialized runners would describe more RRIs, higher running volume, lower QoL, worse sleep habits, and less running enjoyment than low-level specialized runners.

METHODS

Participants

Contact information for middle school and high school athletic directors and cross-country coaches across the United States was retrieved from public online sources (eg, high school athletic associations and web pages of coaches' associations) from January through April 2020. We emailed recruitment materials to athletic directors and coaches with a request to forward them to their schools' cross-country runners. The first round of invitations was sent during January through March 2020, and a follow-up invitation was sent in April 2020. Inclusion criteria were age 9 through 17 years and participation in long-distance running activities such as team or club cross-country, track and field (distances $\geq$800 m), road races, or recreational running. The university's institutional review board approved the study. Parental permission and participant assent were obtained before study enrollment.

Questionnaire

A customized, anonymous, open online questionnaire was administered to participants between January and May 2020 through a password-protected Qualtrics database (SAP SE). The Checklist for Reporting Results of Internet E-Surveys (CHERRIES) was used to improve study quality.[19] The questionnaire had no time limit for completion (median time to complete = 12 minutes) and consisted of 112 items related to demographics, injury history, sport specialization, running volume, QoL, sleep habits, and running enjoyment. Questions were divided among a minimum of 10 screens and presented in a consistent order with adaptive questioning depending on responses. Participants were encouraged to have parental assistance while completing the questionnaire.

Sport Specialization. A previously established 3-point scale was used to determine sport specialization level (low, moderate, or high).[15] One point was scored for each *yes* response to the following items: (1) the participant quit another sport to focus on a main sport (ie, running), (2) the main sport (ie, running) was more important than any other sport, and 3) the participant trained or participated in the main sport (ie, running) >8 months of the year. Due to concerns about misclassifying highly specialized athletes as moderately specialized, we awarded an additional point if the participant never quit any other sport and never played any other sport.[9] They were classified as low-, moderate-, or high-level specialized runners, which corresponded to scores of 0–1, 2, and 3, respectively.

Running-Related Injury. Participants were asked to report whether they had sustained a low back or lower extremity RRI within the last 12 months. An *RRI* was defined as pain in the low back or lower limb that caused a restriction or stoppage of running (distance, speed, duration, or training) for $\geq$7 days or 3 consecutive scheduled sessions or required the individual to consult a physician or other health professional.[20] If an RRI was reported within the last 12 months, the participant indicated the number of RRIs sustained, whether he or she was currently injured, and the injury location (ie, low back; pelvis, hip, or upper leg; knee; Achilles, calf, or lower leg; or ankle or foot region).

Running Volume. Participants were asked to report running volume, including the average number of runs and distance run per week (miles) over the last month. Average distance run per week was converted to kilometers, and average distance per run was calculated by dividing average weekly distance run by average number of runs per week. Participants also reported the number of months per year they competed in long-distance running sports.

Quality of Life and Overall Health. The EQ-5D-Y,[21] an age-friendly version of the EQ-5D, assesses health-related QoL and overall health. The EQ-5D-Y is composed of 5 dimensions on a 3-point scale: mobility, self-care, activity level, pain or discomfort, and feelings of worry or sadness. For each dimension, the individual reports the problems being experienced at the time of completion (*none*, *some*, *a lot*). Participants who reported *some* or *a lot* were placed in a problems group for the appropriate EQ-5D-Y dimension. They also described their overall health using a 100-point VAS (0 = *worst imaginable*, 100 = *best imaginable*).[21]

Sleep Quality. Sleep quality was evaluated using the Pittsburgh Sleep Quality Index (PSQI).[22] On a 4-point scale, the PSQI assesses 7 facets of sleep: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction over the last month. The 7 facets are weighted for calculation of a global PSQI scale ranging from 0 (*no difficulties sleeping*) to 21 (*severe difficulties sleeping*).[22] Sleep duration was reported as the average number of hours of sleep the participant slept per night over the last month.[22]

Running Enjoyment. A 100-point visual analog scale (VAS; 0 = *no enjoyment*, 100 = *full enjoyment*) assessed the participant's enjoyment of running.

Only completed surveys were included in the final study analyses, and individuals were excluded if they described a current RRI or did not report their sex. The IP address was recorded for each person and screened for duplication. If duplicated IP addresses were identified, the responses were checked for originality. Responses from the same IP address were used only if they were clearly different. If no clear difference was observed, only the first response was used in the analysis.

Statistical Analyses

We analyzed the data using RStudio software (version 1.2, RStudio, Inc). Chi-square tests compared differences in frequencies of sport specialization levels by sex. Cochran-Mantel-Haenszel tests compared frequencies of RRIs and reporting problems in each EQ-5D-Y dimension among sport specialization levels and between sexes. Two-way type II analyses of variance (ANOVAs; sport specialization level × sex) were conducted to identify group differences in age, overall health VAS, PSQI global value, hours of sleep per night, distance run per week, average distance per run, and running enjoyment. The interaction term was always nonsignificant ($P > .05$), so we dropped it from the model. Pairwise post hoc analyses with Bonferroni corrections were performed if statistically significant interactions or main effects were identified. We used Poisson regression models to analyze the number of months competing and number of runs per week among sport specialization levels while controlling for sex. Significance was set at $P \leq .05$.

RESULTS

Recruitment materials were emailed to 1433 athletic directors and 3971 middle school and high school cross-country coaches. Of the 750 survey attempts, 550 participants met the inclusion criteria and were enrolled in the study. Of the enrolled participants, 41 were excluded from analysis because they reported a current RRI. Of the 509 enrolled and eligible for the analysis, 102 adolescent boys (95 competitive [93.1%]) and 156 adolescent girls (145 competitive [92.9%]) completed the survey in full (completion rate = 50.7%). Adolescent boys (age = 15.9 ± 0.9 years, range = 13–17 years) were significantly older than girls (age = 15.6 ± 1.4 years, range = 11–17 years; $P = .01$). Chi-square analysis demonstrated no differences in the frequencies of sport specialization levels between adolescent boys and girls ($\chi^2_2 = 2.78$; $P = .25$). Among adolescent boys, 24 participants (23.5%) were classified as specialized at a low level, 38 (37.3%) at a moderate level, and 40 (39.2%) at a high level. Among girls, 46 participants (29.5%) were classified as specialized at a low level, 64 (41.0%) at a moderate level, and 46 (29.5%) at a high level.

Cochran-Mantel-Haenszel tests showed no differences in the frequencies of participants among sport specialization level or by sex (Table 1) for those who reported a previous RRI ($P = .25$). Total injuries cited were 66 in boys and 108 in girls. Also, no differences were noted in the frequencies of RRI location by sport specialization level or sex (Table 1). The most common injury locations for adolescent boys were the knee, upper leg, and ankle or foot and for girls were the lower leg, ankle or foot, and upper leg. Similarly, no differences occurred in the frequencies of participants by sport specialization level or sex for those who reported problems with mobility ($P = .25$), self-care ($P = .30$), activities ($P = .25$), pain ($P = .25$), or feelings of worry or sadness ($P = .27$; Table 2).

Table 1. Injury Locations By Sport Specialization Level and Sex for Adolescent Long-Distance Runners Who Reported a Previous Injury

Variable Sport Specialization Level	No. (% of Sport Specialization Level) Males	Females	P Value
Previous injury			
Low	7 (29.2)	19 (41.3)	.25
Moderate	15 (39.5)	25 (39.1)	
High	15 (37.5)	15 (32.6)	
Location			
Low back			
Low	1 (4.2)	4 (8.7)	.25
Moderate	6 (15.8)	5 (7.8)	
High	2 (5.0)	5 (10.9)	
Upper leg			
Low	1 (4.2)	7 (15.2)	.25
Moderate	6 (15.8)	9 (14.1)	
High	7 (17.5)	6 (13.0)	
Knee			
Low	2 (8.3)	4 (8.7)	.27
Moderate	7 (18.4)	10 (15.6)	
High	8 (20.0)	5 (10.9)	
Lower leg			
Low	3 (12.5)	11 (23.9)	.25
Moderate	4 (10.5)	9 (14.1)	
High	5 (12.5)	9 (19.6)	
Ankle or foot			
Low	7 (29.2)	8 (17.4)	.26
Moderate	4 (10.5)	8 (12.5)	
High	3 (7.5)	8 (17.4)	

Main effects were present by sport specialization level for distance run per week ($P < .001$), average distance per run ($P < .001$), and running enjoyment ($P < .001$; Table 3). Highly specialized runners reported greater weekly distances run ($P < .001$), average distances per run ($P < .001$), and running enjoyment ($P < .001$) than low-level specialized runners, as well as greater weekly distances run ($P < .001$) and average distances per run ($P < .001$) than moderate-level specialized runners. Moderately specialized runners described greater weekly distances run ($P < .01$) and running enjoyment ($P < .01$) than low-level specialized runners. Main effects by sex (Table 3) were noted for sleep quality ($P = .02$), distance run per week ($P = .04$) and average distance per run ($P = .01$). Boys displayed lower PSQI global scores (ie, better sleep quality) and greater weekly distances and average distances per run than girls. No main effects for sport specialization level or sex were shown for overall health or sleep duration (Table 3).

When we controlled for sex, a Poisson regression model indicated that highly specialized runners competed 1.45 and 1.88 times more months per year than moderate-level

Table 2. Reported Quality of Life Problems By Sport Specialization Level and Sex of Adolescent Long-Distance Runners

Problem Sport Specialization Level	No. (% of Sport Specialization Level) Males	Females	*P* Value
Mobility			
Low	2 (8.3)	2 (4.3)	.25
Moderate	4 (10.5)	4 (6.3)	
High	2 (5.0)	3 (6.5)	
Self-care			
Low	1 (4.2)	0 (0)	.30
Moderate	0 (0)	0 (0)	
High	2 (5.0)	0 (0)	
Activities			
Low	2 (8.3)	3 (6.5)	.25
Moderate	1 (2.6)	4 (6.3)	
High	4 (10.0)	2 (4.3)	
Pain			
Low	8 (33.3)	25 (54.3)	.25
Moderate	23 (60.5)	35 (54.7)	
High	22 (55.0)	24 (52.2)	
Feelings of worry or sadness			
Low	12 (50.0)	33 (71.7)	.27
Moderate	21 (55.3)	44 (68.8)	
High	25 (62.5)	27 (58.7)	

specialized runners ($P < .001$) and low-level specialized runners ($P < .001$), respectively, whereas moderate-level specialized runners competed 1.30 times more months per year than low-level specialized runners ($P = .001$; Table 4). Similarly, high-level specialized runners completed 1.27 and 1.62 times more runs per week than moderate-level ($P < .001$) and low-level ($P < .001$) specialized runners, respectively, whereas moderate-level specialized runners completed 1.27 times more runs per week than low-level specialized runners ($P = .003$).

DISCUSSION

To our knowledge, we are the first to investigate differences in RRIs, running volume, QoL, sleep habits, and running enjoyment in male and female middle school and high school long-distance runners at different sport specialization levels. In agreement with our hypotheses, male and female high-level specialized runners reported greater running volumes than male and female low-level specialized runners. However, contrary to our hypotheses, high-level specialized male and female runners enjoyed running more than low-level specialized runners did. Furthermore, no differences were present for RRIs, QoL, or sleep habits among sport specialization levels for either sex.

Table 3. Adolescent Long Distance Runners' Characteristics by Sport Specialization Level and Sex

Variables Sport Specialization Level	Mean ± SD Males	Females	*P* Value Sport Specialization Level	Sex
Age, y				
Low	15.9 ± 1.0	15.6 ± 1.4	.96	.01[e]
Moderate	15.7 ± 1.0	15.7 ± 1.2		
High	16.1 ± 0.9	15.4 ± 1.0		
Health score				
Low	83.2 ± 15.3	85.6 ± 9.7	.07	.52
Moderate	84.4 ± 11.6	83.9 ± 12.5		
High	89.8 ± 7.9	86.0 ± 10.2		
Pittsburgh Sleep Quality Index score				
Low	4.8 ± 2.3	5.2 ± 2.7	.19	.02[e]
Moderate	4.2 ± 2.3	5.4 ± 2.6		
High	4.0 ± 2.1	4.6 ± 3.1		
Sleep duration, h				
Low	7.9 ± 1.5	7.8 ± 1.2	.11	.24
Moderate	7.6 ± 1.2	7.4 ± 1.5		
High	7.9 ± 1.1	7.7 ± 1.0		
Weekly running distance, km				
Low	18.9 ± 21.1	21.1 ± 19.1	<.001[d]	.04[e]
Moderate	35.2 ± 20.8[a]	29.0 ± 21.9[a]		
High	58.3 ± 22.6[b,c]	45.8 ± 30.9[bc]		
Average running distance, km/run				
Low	5.2 ± 5.3	5.3 ± 4.1	<.001[d]	.01[e]
Moderate	7.4 ± 3.4	6.0 ± 3.6		
High	10.2 ± 2.8[b,c]	7.7 ± 5.1[b,c]		
Running enjoyment score				
Low	77.8 ± 25.1	77.9 ± 17.4	<.001[d]	.58
Moderate	86.2 ± 14.8[a]	85.0 ± 14.0[a]		
High	90.2 ± 9.2[b]	88.5 ± 10.1[b]		

[a] Difference between moderate- and low-level specialized runners.
[b] Difference between high- and low-level specialized runners.
[c] Difference between high- and moderate-level specialized runners.
[d] Difference among sport specialization levels.
[e] Difference between sexes.

Table 4. Poisson Regression Comparisons Among Sport Specialization Levels for Adolescent Long-Distance Runners

Variable, No.	Sport Specialization Comparison	β (95% CI)	Rate Ratio[a] (95% CI)	*P* Value[b]
Months competing	Low vs moderate	0.26 (0.12, 0.39)	1.30 (1.13, 1.45)	<.01
	Low vs high	0.63 (0.51, 0.75)	1.88 (1.67, 2.12)	<.001
	Moderate vs high	0.37 (0.26, 0.48)	1.45 (1.30, 1.62)	<.001
Runs per week	Low vs moderate	0.24 (0.08, 0.39)	1.27 (1.08, 1.48)	<.01
	Low vs high	0.48 (0.33, 0.62)	1.62 (1.39, 1.86)	<.001
	Moderate vs high	0.24 (0.15, 0.33)	1.27 (1.16, 1.39)	<.001

Abbreviation: β, intercept coefficient.

[a] Calculated as $e^{(estimate)}$.

[b] All values indicated differences. Both analyses included sex as a covariate.

Sport Specialization and Injuries

Previous researchers[4,8,10,11,14–17] found that highly specialized adolescent athletes were at a higher risk of injury. However, only 1 of these studies focused on long-distance runners,[17] and long-distance runners were underrepresented in the others. Our results differed from the previous findings in that we observed no difference among sport specialization levels, regardless of sex, in the frequency of runners with a history of RRIs. Possible explanations for the contradictory results are the mixed-sport cohorts in earlier studies[4,8,10,11,14–16] and differences in RRI and sport specialization definitions as well as study designs.[17] Long-distance runners have been underrepresented in mixed-sport cohorts,[4,8,10,11,14–16] and these results may not be fully generalizable to long-distance runners. In our investigation, RRIs were self-reported, whereas in previous studies,[4,10,11,14,16,17] injuries were diagnosed or reported by health care professionals or coaches. Whereas novice adult runners demonstrated[23] high sensitivity and specificity compared to physicians in describing body locations of RRIs, it is unclear whether adolescent runners are able to appropriately self-report an RRI. Thus, the potential for overreporting or underreporting injuries existed in our work. An earlier examination[17] of adolescent female long-distance runners used a prospective design, which likely minimized recall bias, and defined the sport specialization level according to participation volume and participation in nonrunning sports. The cross-sectional design of our study may have introduced recall bias and affected the sport specialization and RRI results.

Sport Specialization Definitions

We defined sport specialization level according to participation volume, a history of quitting other sports, and a report of 1 main sport.[15] The current classification of sport specialization may be insufficiently discriminative for long-distance runners; however, to our knowledge, no researchers have compared sport specialization definitions. Using sport specialization definitions similar to ours, the authors[11] of a prospective study of high school athletes reported higher injury incidences in moderate- and high-level specialized athletes. Yet only 62 (4%) of their participants were cross-country runners, and 52 of these were classified as low-level specialized.[15] These results suggest that caution should be used when generalizing results from a mixed-sport cohort to running sports with smaller sample sizes. Sport-specific adjustments may be necessary for appropriate sport specialization classifications.

General recommendations on limiting participation of 1 sport to <8 months per year[15] exist to reduce the risk of injury. High-level specialized adolescent athletes reported greater training volume than low-level specialized adolescent athletes.[10] Furthermore, adolescent athletes who exceeded the recommended 8 months of training for 1 sport per year were at a higher risk of sustaining an injury then those who trained <8 months per year for a single sport.[10,16] The established guidelines are generally applied to all sports, but whether these guidelines are adequate for adolescent long-distance runners is unclear. In a prospective study of female high school cross-country runners, researchers[17] used 9 months of participating in 1 sport and single-sport status as criteria for sport specialization. They determined that high-level specialized runners were at greater risk of sustaining an RRI than were low-level specialized runners.[17] Participation in multiple sports may be an important factor for adolescent long-distance runners that is not fully captured by the current sport specialization definition. In a study[24] of older elite runners, those who participated in multiple sports as adolescents were half as likely to sustain running-related stress fractures. Specific to middle school and high school long-distance runners, the current sport specialization definition may need to be adjusted to include running-specific criteria such as participating in nonrunning sports, the number of months competing in long-distance running, or average weekly or monthly running distance to properly classify these athletes.

Running Volume

High-level specialized middle school and high school long-distance runners reported greater running volumes than low-level specialized runners. These results supported previous findings[4,10,16] of greater training volumes for more specialized athletes. Our male and female high-level specialized long-distance adolescent runners competed nearly twice as many months per year as low-level specialized runners did. Even though the highly specialized runners exceeded the recommended 8 months of sport participation, we observed no differences in the frequencies of runners who reported injuries among sport specialization levels. The number of months training per year may not be a sufficiently sensitive metric to associate with RRIs in adolescent long-distance runners. Perhaps drastic changes in monthly or weekly running volumes or running pace or intensity are of greater importance than the number of months training. More prospective studies of adolescent long-distance runners are required to determine whether the number of months training and competing, differences in monthly or weekly running volumes, marked changes in these volumes, or interactions between these volumes and other training or physiological and biomechanical factors (eg, joint kinematics and kinetics, lower extremity flexibility and strength) are related to the RRI risk. Understanding these interactions will help coaches and clinicians develop running-specific guidelines for these athletes.

As expected, highly specialized middle and high school long-distance runners ran greater distances per week and more frequently each week, and they achieved longer average distances per run. Furthermore, adolescent boys reported greater distances run per week and average distances per run than girls. To our knowledge, no previous authors have reported weekly running volume according to the sport specialization level and sex of adolescent long-distance runners. Greater running distance has been related[2,25] to an increased injury risk in adolescent runners; however, no guidelines exist for the appropriate distance that adolescent runners should run per week to reduce the risk of sustaining an RRI. Whereas adolescent boys trained at higher volumes than girls, the frequencies of adolescent boys and girls who reported previous injuries were not different. This result might suggest that middle school and high school long-distance male runners may better tolerate greater distances than their female counterparts, but other factors such as running experience and the pace or intensity (eg, slower) of the distance run by adolescent boys may have also played a role. It is possible that sex-specific criteria may be necessary for establishing recommended running volumes. Wide variances were apparent in weekly distances among sport specialization levels and between sexes, yet no differences were present in weekly distances between runners with and those without a history of RRI. It may be appropriate to adapt the sport specialization definition in adolescent long-distance runners to include a weekly distance threshold as well, although as with running volume, this warrants further investigation.

Wellness and Enjoyment

No differences in QoL were evident among sport specialization levels. These results are similar to those in a mixed-sport cohort of adolescent athletes.[8] Higher levels of sport specialization are thought to be associated with greater levels of stress and anxiety.[26] However, we noted no differences among the sport specialization levels in the frequencies of participants reporting problems with feelings of worry or sadness. We found it interesting that more than half of the participants at each sport specialization level conveyed feeling some degree of worry or sadness. Healthy adolescent athletes previously demonstrated[27] better health-related QoL than nonathletes, yet normative data on adolescents were unavailable for the EQ-5D-Y dimensions. Nevertheless, middle school and high school long-distance runners as a whole, regardless of sport specialization level, may be at risk for feelings of worry or sadness.

High-level specialized male and female runners reported greater enjoyment running than low-level specialized runners. Olympic-level gymnasts who increased training volume at an earlier age reported less enjoyment in their sport than subelite international-level gymnasts.[12] Our runners may not have been as highly specialized as those elite athletes, or the current sport specialization definition may not have identified extremely high-level specialized athletes. Further work is necessary to understand how confounding variables such as motivators (eg, health benefits, stress relief, parental influence, coaching strategies) influence running enjoyment in male and female adolescent long-distance runners. Also, longitudinal studies are warranted to determine how the enjoyment level changes over time as an athlete remains highly specialized.

No differences were observed in sleep quantity or quality among sport specialization levels; however, males reported better sleep quality than females. Authors[28] of a systematic review indicated that adolescent athletes were at greater risk of sleep deprivation. In a recent investigation[13] of female adolescent soccer players, sleep duration did not differ among sport specialization levels, but highly specialized soccer players depicted worse sleep quality. How *sport specialization* and *sleep quality* were defined in that study is unclear, which may offer a possible explanation for the contrasting results. Based on our data, the average sleep duration of low-, moderate-, and high-level specialized male and female runners did not meet the recommended 8 to 10 hours of sleep per night for adolescents aged 13 to 18 years.[29] Furthermore, their sleep quality was similar to the values for healthy adolescent boys and girls, regardless of sport specialization level.[30] Thus, sport specialization may not be detrimental to sleep quality or quantity in adolescent long-distance runners; however, middle and high school cross-country runners may be at risk of not meeting the recommended hours of sleep per night.

Limitations

These results should be interpreted in the context of the study's limitations. The data were not collected during cross-country and track seasons. Running habits may be different when athletes are out of season, and further exploration during the season is warranted. As stated earlier, the cross-sectional design of the study may have introduced recall bias. We attempted to limit the influence of recall bias by restricting the timeline of recalled injuries to the previous year and running habits to the previous month. Injury occurrence may be more sensitive to the timing of changes in running volume, and week-to-week measures may be more appropriate than month-to-month measures. We also failed to capture running experience, which may influence injury rates. Currently, no universally accepted criteria exist for identifying RRIs in adolescent cross-country runners. The RRI definition we applied was from a consensus statement specific to recreational adult runners.[20] The definition may not be applicable to middle and high school cross-country runners, whose season is more condensed and compressed. Participants were also encouraged to have parental assistance in answering the questions. However, how often parents assisted in the completion of the questionnaire is unknown, and the accuracy of self-reported data may have been affected by the lack of parental assistance. Future research is recommended to address these limitations.

CONCLUSIONS

We are the first to investigate differences among sport specialization levels in male and female middle school and high school long-distance runners. Male and female high-level specialized middle school and high school long-distance runners reported greater running volume and running enjoyment than low-level specialized runners. No differences were found in RRIs, QoL, or sleep habits among specialization levels. Highly specialized middle and high school long-distance runners did not report a greater number of RRIs, lower QoL, or lower sleep quality or quantity as we expected.

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