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Original Research

Training Load and Injury Among Middle School–Aged Athletes

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Context: Young athletes are encouraged to participate in high-intensity sport programs. However, most research on the association between training volume (TV) and injury has been performed on adult or professional athletes.

Objective: To evaluate the association between acute and chronic TV (hours/week) and reported injury (*yes*/*no*) and evaluate the relationship between acute : chronic TV and injury while controlling for sex, age, and prior injury in young athletes.

Design: Cohort study.

Setting: Online surveys.

Patients or Other Participants: Middle school-aged adolescents.

Main Outcome Measure(s): We conducted a baseline survey at the start of the 2017–2018 academic year. The baseline survey solicited information regarding demographics, injury history, and primary sport. Subsequent surveys were delivered electronically at the start of each week. Information obtained with the weekly survey included weekly TV and injuries sustained the previous week. Injuries were reported and classified (eg, acute or gradual onset) by the participants. Weekly TV was aggregated as rolling averages over the prior 2, 3, and 4 weeks. Acute:chronic TV was calculated for each participant for every week as the prior week TV divided by the TV during the prior 2 (1 : 2), 3 (1 : 3), and 4 (1 : 4) weeks of the study period.

Results: A total of 244 recruits participated. Higher average TV over the prior 4 weeks (odds ratio [OR] = 0.97; 95% confidence interval [CI] = 0.93, 1.00; $P = .05$) was associated with fewer reported injuries. Additionally, higher average TV over the prior 2 (OR = 0.96; 95% CI = 0.93, 0.99; $P = .04$), 3 (OR = 0.95; 95% CI = 0.91, 0.99; $P = .02$), and 4 (OR = 0.95; 95% CI = 0.91, 0.99; $P = .05$) weeks was associated with fewer reported acute injuries the following week. Acute:chronic TV and any injury type were not related.

Conclusions: Consistent, higher levels of physical activity may offer protection against acute injury in young athletes.

Key Words: overuse injury, sport specialization, youth, adolescent athletes, training volume

Key Points

- Greater chronic training volume may reduce the risk of acute injury in adolescent athletes.
- Higher chronic training volume was not associated with overuse injuries in adolescent athletes.
- Acute:chronic training volume ratios were not associated with subsequent injury in adolescent athletes.

Sport participation rates among children and early adolescents in the United States remain high, with 69% of youths aged 6 to 12 years participating in either a team or individual organized sport.[1,2] Additionally, young athletes are being encouraged to participate in high-intensity programs intended to improve skills.[3] Many youth athletes increase their training volume (TV) due to a variety of factors, such as parental pressure, coach recommendations, pursuit of a collegiate athletic scholarship, or even professional aspirations.[4–6] Youth athletes often feel that playing with an additional club team or specializing in a single sport is necessary to make their high school team.[7] As a result of additional club participation, many youth athletes undergo year-round intensive training, often in a single sport.

Intentional year-round participation in a single sport to the exclusion of other sports has been related to overuse injuries in adolescent populations,[4,8–10] which has prompted organizations to make recommendations for safe sport participation.[11,12] Furthermore, adolescent athletes who intentionally train year-round participate in more hours per week than other athletes.[10,13] Researchers[4,9,10] suggested that athletes should not spend more hours per week participating in organized sport than their chronological age. In one study[4] of high school athletes aged 14 to 19 years, exposure of more than 16 hours of sport participation per week was strongly associated with sport-related injury (odds ratio [OR] = 8.52; 95% confidence interval [CI] = 5.82, 12.47; $P < .001$).

Most authors have focused on the relationship between training load and injury while considering both duration and intensity. For example, higher daily and prior-day internal training loads (according to the session rating of perceived exertion) were related to a higher incidence of injuries among female youth soccer athletes.[14] In addition, the *acute:chronic workload ratio* (ACWR), defined as the workload from the prior week divided by the 4-week rolling average workload, has been associated with injury.[15,16] Specifically, a nonlinear relationship has been suggested, such that large increases (very high acute loads relative to the last 4 weeks) or decreases (very low acute loads relative to the last 4 weeks) in this ratio appear to be associated with

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an increased risk of subsequent injury.[17–23] However, some[24] have questioned the interpretation of this relationship and raised the possibility of spurious correlations between ACWR and injury, as the acute training load is part of both the numerator and denominator. Additionally, variations in training schedule may confound the relationship between ACWR and injury.[25] Yet research in preadolescent athletes to evaluate the association between acute on chronic TV and injury risk is limited.

In an attempt to reduce the risk of injuries among youth athletes, the American Medical Society for Sports Medicine[11] has provided recommendations regarding weekly organized sport participation by this population. Unfortunately, earlier studies[26,27] of youth sport participation often did not incorporate or account for TV as it is related to injury and were focused primarily on older adolescent athletes. Compared with measures of internal and external training load, guidelines about hours of weekly participation may be more easily understood and implemented by parents of younger children. For example, a relationship between TV and shoulder injury rates among elite youth handball athletes (adolescents aged 14–18) was identified.[28] Still, to our knowledge, the relationships between TV and injury risk have not been prospectively examined in middle school athletes (adolescents aged 10–14 years) across a variety of sports and injury types. Therefore, the purpose of our study was to (1) prospectively evaluate the association between acute and chronic TV (hours per week) and overall, acute, and overuse injuries; and (2) evaluate the relationship between various ratios of acute:chronic TV and injury while controlling for sex, age, and prior injury in middle school-aged athletes.

METHODS

This study was approved by the Institutional Review Board of the University of Wisconsin–Madison. We followed a prospective cohort design that involved weekly anonymous surveys using Qualtrics (Provo, UT). Parents of youth athletes were initially contacted by email to participate in the weekly anonymous survey. The weekly survey lasted for 39 weeks of the academic year, starting in September of 2017. Data were included in the final analysis if the participant completed 80% or more of the weekly surveys. Children and their parents were instructed to complete the surveys together, and the data were recorded in a deidentified format.

Survey

A baseline survey was conducted at the start of the 2017–2018 academic year. The baseline survey solicited information regarding demographics, injury history, primary sport (if applicable), and sport participation volume (months per year in the primary sport). Subsequent surveys were delivered electronically at the start of each week to solicit information regarding the prior 7 days. Information obtained with the weekly survey addressed *weekly TV* (defined as total hours spent practicing and playing organized sport) and any injuries sustained during that time. The location (eg, head, shoulder, elbow) and type of musculoskeletal injury sustained (eg, sprain, strain, bruise, fracture, tendinitis, or other), as well as the mechanism of the injury (eg, overuse, direct contact, or noncontact) were identified. An *overuse injury* was operationally defined as an injury that reportedly occurred due to a gradual onset and was classified as a sprain, strain, tendinitis, or stress fracture. An *acute injury* was operationally defined as a reported injury for which the participant identified a distinct isolated incident (selecting a contact or noncontact injury mechanism) that caused the injury and was classified as a sprain, strain, bruise, or fracture.

Statistical Analysis

The data are presented as means and standard deviations for continuous variables and as the number and frequency for categorical variables. We compared TV between age groups using least squares means from a linear mixed-effects model, with age as a fixed effect and each individual as a random effect. For each participant during each week of the study period, weekly TV was aggregated as rolling averages over the prior 2, 3, and 4 weeks. Acute:chronic TV was calculated for each individual for every week as the prior week TV divided by the TV in the prior 2 (1 : 2), 3 (1 : 3), and 4 (1 : 4) weeks during the study period. For each of the 7 TV variables, separate mixed-effects logistic regression models were conducted to identify their association with any injury during the following 7 days (1 week) by using the TV variable, age, sex, and prior injury as fixed effects and each individual as a random effect. This method was repeated using the same covariates to identify associations between acute and overuse injuries separately. Athletes who had not yet recovered from a previous week's injury were excluded from the logistic models until their injury had resolved. Statistical significance was set a priori at $P < .05$, and all analyses were performed using R statistical software (version 3.4.2; The R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Of an initial 278 participants who completed the baseline survey, 244 (88%) completed 80% or more of the weekly surveys, and 125 (51%) completed 100% of the surveys. Participants reported their primary sports as basketball (n = 85, 35%), soccer (29, 12%), volleyball (26, 11%), tennis (21, 9%), baseball (20, 8%), football (16, 7%), cross-country (13, 5%), softball (11, 5%), swimming or diving (11, 5%), ice hockey (3, 1%), cheer or dance (2, 1%), gymnastics (1, <1%), wrestling (1, <1%), or other (5, 2%). Among the 244 participants included in the analysis (Table 1), 117 (48%) reported 219 injuries, with 149 being classified as acute and 70 as chronic or overuse (Figure). This represented an overall injury rate of 2.44 injuries per 1000 hours of physical activity. Baseline measures including age, sex, and prior injury were not different between injured and uninjured participants (Table 1). Weekly reported hours per week in organized sport were not different among 10-, 11-, 12-, 13-, or 14-year-old participants (Table 2). An increase in the average TV over the prior 4 weeks decreased the risk of reporting an acute injury (OR = 0.97; 95% CI = 0.93, 1.00; $P = .05$; Table 3). Additionally, higher average TV over the prior 2 (OR = 0.96; 95% CI = 0.93, 0.99; $P = .04$), 3 (OR = 0.95; 95% CI = 0.91, 0.99; $P = .02$), and 4 (OR = 0.95; 95% CI = 0.91, 0.99; $P = .05$) weeks was associated with fewer reported acute injuries the following week (Table 3). However, no

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Table 1. Baseline Data for Injured and Uninjured Athletes[a]

Variable	Group		
	Injured	Uninjured	Overall
Male sex, n (%)	46 (39)	74 (59)	120 (49)
Age, y[b]	12.1 ± 1.2	12.1 ± 1.2	12.1 ± 1.2
Prior injury (*yes*), n (%)	47 (39)	98 (65)	135 (55)
Prior injuries, No.[b]	1.0 ± 1.1	1.0 ± 1.0	1.0 ± 1.0
Weekly total activity, h[b]	19.7 ± 10	18.9 ± 8.8	19.2 ± 9.2
Weekly organized activity, h[b]	12.9 ± 7.9	12.8 ± 7.7	12.8 ± 7.8
Weekly unorganized activity, h[b]	6.8 ± 6.5	6.1 ± 4.6	6.4 ± 5.3
Organized/unorganized sports ratio[b]	3.5 ± 3.6	3.4 ± 3.4	3.4 ± 3.5

[a] The injured and uninjured groups were not different for any baseline variable.
[b] Data are represented as mean ± SD.

duration of prior TV (prior week or prior 2, 3, or 4 weeks) was significantly related to overuse injury (Table 3). Similarly, no significant relationship was present between acute:chronic TV and overall, acute, or overuse injury the following week (Table 3).

DISCUSSION

Our primary finding was that higher chronic TV was associated with a reduced risk of injury the following week after adjusting for age, sex, and prior injury. To the best of our knowledge, we are the first to prospectively evaluate the relationship between various durations of prior TV and injury risk in a population of middle school-aged athletes from various sports[28] and suggest that athletes with higher chronic TVs may gain some protective benefit against acute injury. Although this finding has been confirmed in studies of adult athletes,[15,29–31] we were the first to demonstrate this in a middle school-aged population while controlling for previous injury.

We explored ratios of acute:chronic TV to determine whether changes in participation hours relative to the habitual level of activity were associated with subsequent injury, but they were not. This result is different from that in previous research[28] on youth handball players in which a 60% increase in handball participation compared with the previous 4 weeks increased the risk of shoulder injuries. These variations may reflect differences in methods or populations. Our measures were calculated in a similar way to ACWR; therefore, the objections regarding the ACWR calculation may apply to our calculations as well.[24] Traditional measures of ACWR incorporate both training duration and intensity and have been associated with injury in other studies.[15,17,29,30] However, important methodologic differences in our work could account for these differences. Our middle school athletes did not report changes in weekly TV that were as significant as those seen in college-aged or professional athletes. We observed relatively small variances in TV and ratio variables. This may have simply resulted in fewer times when the ratio reached a level that has been suggested to increase the injury risk in older athletes. However, we found that relative fluctuations in TV in younger athletes were not related to injury risk, whereas a chronic and consistent TV may help reduce the injury risk

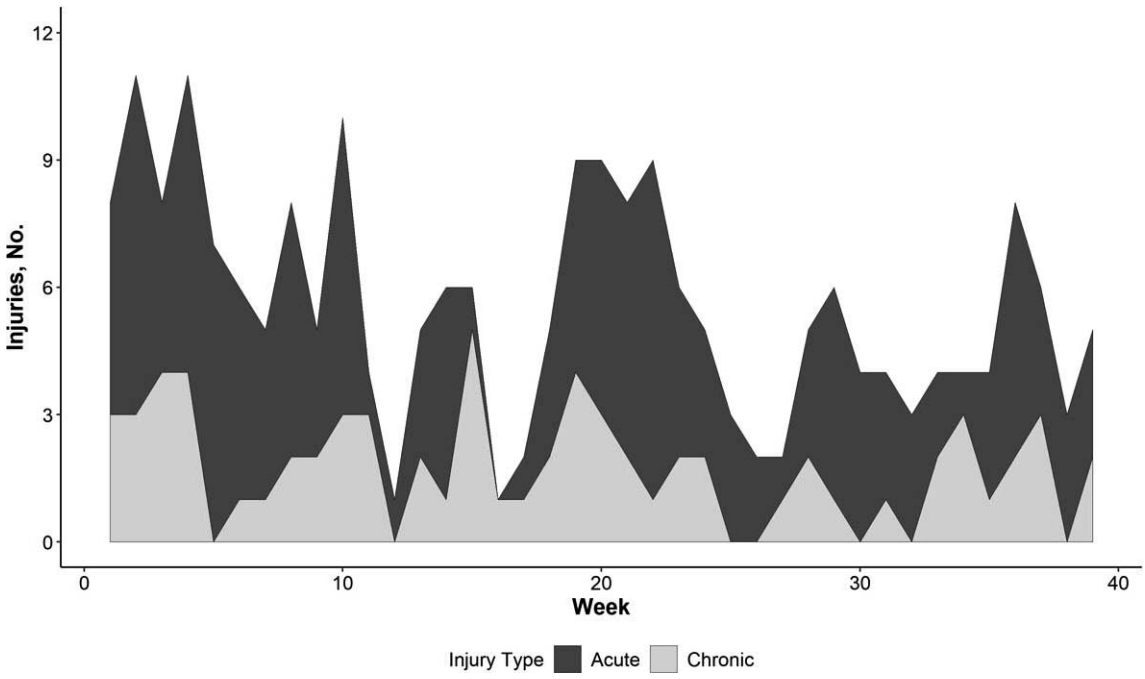

Figure. Number of injuries sustained each week during the study period.

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Table 2. Weekly Training Volume (h) by Age Group

Age, y (Mean ± SD [Range])				
10	11	12	13	14
10.4 ± 1.2 (0–28)	10.2 ± 0.78 (0–28)	9.25 ± 0.72 (0–28)	9.96 ± 0.72 (0–29)	9.33 ± 1.1 (0–27)

in younger athletes. More research is needed to confirm this theory.

Although higher chronic TV in the present study was associated with a reduced injury risk the following week, this does not necessarily mean that higher and higher TVs will offer more and more protection. The average TV among our participants was typically 10 to 11 hours per week and rarely reached a level that would be considered dangerous based on recent recommendations.[32] We cannot directly address this factor using our data, yet a limit beyond which the benefit of higher chronic TV plateaus in this population seems possible. An unexpected finding was that higher chronic TV was related to acute injuries and not chronic injuries. Previous investigators[27] identified that high-volume, year-round participation in a single sport may be related to an increased risk of overuse injuries. Increases in acute training load negatively affected a number of measures of subjective wellbeing, including fatigue, mood, stress, and soreness, which were risk factors for injury.[33] The specific mechanisms for this relationship are not clear; psychological states, such as increased stress, may increase the risk for injury through physiological (eg, increased muscle tension) or psychological (eg, distractibility and poor decision-making) mechanisms.[34–36] Within our group of middle school athletes, higher levels of chronic TV may lead to fitness increases that not only improve the tolerance of physical constructs to increased loads but also attenuate the impairments in subjective wellbeing after acute increases in TV, thereby reducing the risk of subsequent acute injury.

Finally, our results may differ from those of other studies[15,29–31] because earlier authors failed to control for prior injury in the risk prediction model. Previous injury has been consistently identified as being associated with future injury, and adjusting for this factor may help clarify the true role of risk factors, such as TV, by eliminating the potential confounding role of prior injury. This may be particularly true among youth athletes who are involved in high volumes of year-round sport participation, which is associated with both increased TV and higher rates of prior injury.

Limitations

This study had several important limitations. First, we measured TV in hours of activity, without a measure of intensity or a direct measure of external workload. Although those latter measures might better clarify the true physiological stress experienced by each participant, hours of activity per week is a simple observable measure for parents, and TV recommendations for young athlete safety are more applicable than other direct measures of internal or external workload. Although we collected prospective data over an entire year, this was a relatively small study and may not have been adequately powered to identify relationships between TV durations or ratios and specific injury types. Despite efforts to promote compliance with the data collection, some participants failed to complete the required 80% of the weekly surveys, and their data had to be excluded. Debate is ongoing as to the most appropriate methods for calculating the acute:chronic ratio. We used a moving average, but some researchers[37] have suggested that an exponentially weighted moving average is more appropriate. Finally, we included young athletes from different sports, and thus, our findings may not be generalizable to other populations of athletes, such as football players or gymnasts. Despite the prospective nature of our study, we used surveys that required the recollection of previous events. Therefore, recall bias and misrepresentation of injury data by participants were possibilities. However, we tried to reduce participant confusion about terminology by encouraging a parent to take the survey with the child and by providing descriptions within the survey to help define potentially difficult language.

CONCLUSIONS

Higher chronic TV was associated with a reduced risk of injury the following week among middle school-aged

Table 3. Mixed-Effects Logistic Regression Model Results for All, Acute, and Chronic Injuries

		Injuries					
		All		Acute		Chronic	
Variable		OR (95% CI)	*P* Value	OR (95% CI)	*P* Value	OR (95% CI)	*P* Value
Prior week(s)							
	1	0.97 (0.95, 1.01)	.11	0.97 (0.94, 1.00)	.09	0.99 (0.95, 1.03)	.67
	2	0.98 (0.95, 1.01)	.16	0.96 (0.93, 0.99)	**.04**[a]	1.01 (0.96, 1.05)	.78
	3	0.97 (0.94, 1.00)	.08	0.95 (0.91, 0.99)	**.02**	1.01 (0.96, 1.06)	.76
	4	0.97 (0.93, 1.00)	**.05**	0.95 (0.91, 0.99)	**.02**	1.00 (0.95, 1.05)	.88
Acute:chronic workload ratio							
	1 wk : 2 wk	0.87 (0.58, 1.30)	.65	0.92 (0.63, 1.30)	.91	0.70 (0.35, 1.42)	.33
	1 wk : 3 wk	0.93 (0.67, 1.29)	.67	1.00 (0.68, 1.47)	1.00	0.80 (0.44, 1.45)	.47
	1 wk : 4 wk	0.90 (0.66, 1.23)	.50	0.90 (0.621, 1.30)	.57	0.91 (0.52, 1.58)	.74

Abbreviations: CI, confidence interval; OR, odds ratio.

[a] *P* values in bold are significant.

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athletes, even after adjusting for age, sex, and prior injury. Specifically, higher 2-, 3-, and 4-week TV was associated with a decreased risk of acute injuries, and acute or chronic TV was not related to overuse injury the following week. No TV ratio was associated with overall, acute, or overuse injury in this population. These results suggest that consistent, higher levels of physical activity may offer protection against acute injury in young athletes.

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