Original Research

A Comparison of Factors Associated with Running-Related Injuries between Adult and Adolescent Runners

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Background
There are multiple personal and environmental factors that influence the risk of developing running-related injuries (RRI). However, it is unclear how these key clinical factors differ between adult and adolescent runners.

Purpose
The purpose of this study was to compare anthropometric, training, and self-reported outcomes among adult and adolescent runners with and without lower extremity musculoskeletal RRs.

Study Design
Cross-sectional study.

Methods
Questionnaire responses and clinical assessment data were extracted from 38 adult runners (F: 25, M: 13; median age: 25 [range 18-36]) and 91 adolescent runners (F: 56, M: 35; median age: 15 [range 14-16]) who underwent a physical injury prevention evaluation at a hospital-affiliated sports injury prevention center between 2013 and 2021. Participants were sub-grouped into those with (adults: 25; adolescents: 38) and those without (adults: 13; adolescents: 53) a history of self-reported RRs based on questionnaire responses. Multivariate analyses of covariance (MANCOVA) covarying for gender were conducted to compare outcomes across groups.

Results
Adult runners had lower Functional Movement Screen™ (FMS™) scores (mean differences [MD]: -1.4, p=0.01), were more likely to report intentional weight-loss to improve athletic performance (% difference: 33.0%; p<.001), and more frequently included resistance training into their training routines (% difference: 21.0%, p=0.01) compared to adolescents. Those with a history of RRs were more likely to report intentional weight-loss compared to uninjured runners (% difference: 21.5; p=0.02) and had shorter single leg bridge durations than those without RRs (RRI: 57.9±30, uninjured: 72.0±44, p=0.01).

Conclusion
The findings indicate that addressing aspects of biomechanics identified by the FMS™ and behaviors of weight loss as an effort to improve performance may represent targets for the prevention of RRs for adult and adolescent runners, given the association with history of RRs.

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Level of Evidence

INTRODUCTION

Runners of all ages and abilities are susceptible to musculoskeletal running-related injuries (RRIs) with average incidence rates ranging between 15-62% across epidemiological studies.\(^1\) Many RRIs result in time-loss from sport,\(^4,5\) and often lead to re-injury throughout athletes’ careers.\(^1,6,7\) There are considerable physical and mental health consequences as a result of pausing or stopping running participation due to injury.\(^8-10\) These concerns highlight the need to move towards the prevention of RRIs.

There are numerous personal and environmental factors that influence runners’ tissue load tolerance and contribute to the development of RRIs.\(^6,11-13\) Running imposes considerable cumulative loads on lower extremity static and dynamic structures, with peak forces reaching approximately two- to three-times a runner’s body weight per step.\(^14\) As such, RRIs are often attributed to altered lower extremity alignment,\(^1,5,16\) limited range of motion at the foot and ankle,\(^17,18\) altered functional movement patterns during fundamental tasks,\(^19,20\) and decreased lower extremity muscle strength that inherently limit load attenuation.\(^5,21,22\) Furthermore, additional intrinsic dietary considerations relating to relative energy deficiency in sport (RED-S) have been consistently linked with repetitive stress RRIs.\(^23\) In conjunction with these personal factors, training errors that predispose the body to abrupt increases in running volume and higher training intensities have been frequently attributed to the risk of developing RRIs.\(^1,5,24,25\)

The majority of these aforementioned risk factor assessments have been investigated in adult runners.

Youth athletes undergo substantial developmental changes and periods of rapid growth that influence these factors and subsequent responses to environmental stresses.\(^26,27\) As such, the risk factors noted among adult runners cannot validly be extrapolated to adolescent runners. While there have been increased efforts to evaluate risk factors for RRIs among adolescent runners,\(^6,27\) there are no known studies that have explicitly compared factors between adult and adolescent runners. Specifically a recent youth running consensus statement reflected a dearth in available information on biomechanical factors contributing to RRIs, and highlighted the need to fill in this gap in knowledge.\(^6\) Such a comparison would provide clinicians with information on age-related adaptations and insights into specific risk factors for RRIs with which they might hone future injury prevention efforts.

The purpose of this study was to compare anthropometric, training, and wellness factors among adult and adolescent runners with and without a history of lower extremity musculoskeletal RRIs. The primary hypothesis was that there would be significant differences for clinical measures and training volume between age groups due to developmental differences. It was additionally anticipated that lower FMS™ scores, lower strength and muscular endurance, and more weight-loss behaviors among runners with a history of RRIs compared to those without a history of RRIs.

METHODS

This was a cross-sectional study of existing data from adult (≥18 years of age) and adolescent (<18 years of age) male and female athletes who underwent an Injury Prevention Evaluation at a hospital-affiliated sports injury prevention center between the years 2015 and 2021 (1,051 athletes total in complete dataset). Participants were included in this analysis if they indicated that their primary sport was cross-country, long-distance running, or track (distance running events only; 800m+), and reported that they either had no lower extremity injury history, or that they had a running-related lower extremity injury. Athletes with non-running-related injuries or incomplete data were excluded from analyses. This study was approved by the hospital’s Institutional Review Board (IRB-P00016162), and informed consent was waived due to the retrospective nature of the study.

INJURY PREVENTION EVALUATION

Injury prevention evaluations (IPEs) are designed to measure potential risk factors for injury, determined by the athletes’ sports, and ultimately develop a prescription for reducing the risk of injury by addressing modifiable risk factors or augmenting training to offset non-modifiable risk factors. IPEs are completed when athletes are uninjured. During an IPE, athletes completed a questionnaire that included demographic variables; sport participation; training volume, intensity, and frequency; inclusion of resistance training into their training regimen; weekday sleep quantity; and intentional weight-loss to improve athletic performance. The questionnaire was generated by a local expert panel of physicians treating adolescent athletes; and questions pertaining to weekday sleep quantity using the validated Patient-Reported Outcomes Information System (PROMIS) Pediatric Daytime Sleepiness Scale,\(^28\) and weight-loss using the Food Frequency Questionnaire.\(^29\) Participants reported a history of sport-related injuries ever incurred during sport participation and treated by a medical doctor from 25 possible diagnoses (Appendix 1), including which sport they were participating in when they developed the injury. Only injuries incurred during running were included in analyses, and these data were used to group adult and adolescent runners into RRI and uninjured groups.

Following the intake questionnaire, injury prevention specialists (athletic trainers or strength and conditioning specialists with master’s level training in kinesiology) conducted a comprehensive clinical assessment for each athlete. Based on currently available literature and clinical expertise, data was extracted pertaining to quadriceps angle (Q-angle),\(^30\) leg length,\(^31\) hip abduction strength,\(^21,22,22,22,32,33\) dorsiflexion range of motion,\(^18,34\) single leg bridge
(in seconds), and the FMS™ screen composite score.\textsuperscript{20,35} Handheld goniometers and dynamometers were used to conduct physical assessments using standard clinical methods.\textsuperscript{36,37}

STATISTICAL ANALYSES

Personal characteristics data were not normally distributed (p<0.05), and, as such, median and interquartile range summary statistics, Mann-Whitney U tests (continuous outcomes), and Chi-square tests (categorical outcomes) were used to compare demographics and anthropometrics by age group (adults, adolescents) and injury history (RRI, uninjured). Questionnaire and physical assessment outcome measures met assumptions for normality, and, therefore, parametric tests were used for statistical analyses. Multivariate analyses of covariance (MANCOVAs) covarying for gender were conducted to compare questionnaire and physical assessment measures across age groups and injury history categories. Alpha was set a priori to .05, and Tukey’s post-hoc assessments were conducted in the event of significant group-level differences or interactions.

RESULTS

There were 129 runners that met the inclusion criteria for this study (38 adults [25 RRI, 13 Uninjured], 91 adolescents [38 RRI, 53 Uninjured]) comprising 12.3% of IPE athlete database. (Table 1). The majority of runners participated in track running events (43.4%), and were white (89.9%). Past RRIs self-reported included ankle sprains (49.2%), shin splints (25.4%), lower extremity stress fractures (20.6%), and plantar fasciitis (4.8%). Adult runners had higher BMIs compared to adolescent runners, and a larger proportion of adolescent runners ran cross-country compared to adults (Table 1).

Adult runners more frequently reported intentional weight-loss to improve athletic performance (47% of adults vs. 14% of adolescents; p<0.001; Table 2), and had lower FMS™ composite scores compared to adolescent runners (Mean Difference with Standard Error [MD]: -1.5 [0.6], p=0.02). Similarly, runners with a history of RRIs more frequently reported intentional weight-loss to improve athletic performance (34.9% RRI vs. 13.6% Uninjured, p=0.02), and had lower FMS™ composite scores than uninjured runners (MD: -1.4 [0.5], p=0.01; Table 2).

Adult runners more frequently included resistance training into their training regimens compared to adolescent counterparts (72% of adults vs. 47% of adolescents; p=0.01; Table 2), however, was not significantly different for those with and without RRIs. Regardless of age, runners with a history of RRIs had shorter single leg bridge durations than uninjured runners (MD: -14.1s [8.1s], p=0.01; Table 2). There were no significant interactions between age by injury group for any of the clinical outcomes assessed in the analyses.

DISCUSSION

This is the first study that has compared adult and adolescent runners with and without RRIs to determine if there were age-related differences across physical, training, and self-reported factors. The group-level comparisons reflected key differences in weight-loss behaviors and FMS™ scores between adults and adolescents, and between injured and uninjured runners. However, there were no identified age by injury interactions for any of the measures, indicating similar risk factors may contribute to the development of RRIs for adult and adolescent runners. Clinicians may use this information to guide future injury prevention efforts.

CLINICAL ASSESSMENTS

Adolescent and uninjured runners had higher movement quality scores than adult and runners with a history of RRIs, respectively. Previous studies have identified that FMS™ performance scores decrease with older age even among physically active adults.\textsuperscript{35} However, physically active adolescents have better FMS™ scores than physically inactive adolescents, attributed to improved muscular coordination through early sport participation.\textsuperscript{36} Furthermore, studies show that tactical athletes with FMS™ scores less than 14 are at increased risk of sustaining musculoskeletal injuries.\textsuperscript{19,20} This same association has not previously been established in RRIs; however, the current findings indicate that there is an association between lower FMS™ scores and RRIs history overall, but not disproportionately affected by runners’ age.

Contrary to the proposed hypotheses, there were no identified significant differences between age nor injury groups for hip abduction strength or dorsi/flexion ROM measures. Previous studies present conflicting findings on lower extremity strength measures in relationship to injury development.\textsuperscript{21,22,39} The most consistent evidence indicates that gluteal muscle weakness is associated with patellofemoral pain (PFP)\textsuperscript{15,21,40}; however, no runners had PFP in our sample. Other assessments, however, have identified inadequate pelvic control, which has been attributed to poor muscular endurance, as a risk factor for injury across lower extremity injury types.\textsuperscript{32,41,42} In our study, those with a history of RRIs had significantly decreased single leg bridge duration compared to the uninjured group, supporting the association between impaired neuromuscular control and injury risk. Addressing gluteal endurance among runners might improve pelvic control during sustained activity.\textsuperscript{43}

TRAINING FACTORS

Running training volume and strenuous exercise frequency as a proxy for intensity were similar across age groups and between injured and uninjured groups. This finding may be partially attributed to the timing of the IPE assessment, as those with a history RRIs may have adjusted their training regimens due to injury. Additionally, this study attempted to measure a different facet of training volume.
Table 1. Comparison of adult and adolescent runners with and without running-related injuries.

| Variable                      | Adult Runners | Adolescent Runners | p-value (age groups) | p-value (injury status) |
|-------------------------------|---------------|--------------------|----------------------|-------------------------|
| **Gender**                   |               |                    |                      |                         |
| F: 9, M: 4                   | F: 16, M: 9   |                    | 0.33                 | 0.72                    |
| **Age (years)**              | 24 (21, 43)   | 15 (13, 15)        | 0.001*               | 0.13                    |
| **Race**                     | White (N=11)  | White (N=46)       |                      |                         |
| Black (N=1)                  | Black (N=23)  | Black (N=2)        | 0.89                 | 0.32                    |
| Prefer not to answer (N=1)   | Asian (N=1)   | Asian (N=3)        |                      |                         |
| **BMI (kg/m^2)**             | 21.7 (19.9, 24.8) | 20.0 (18.3, 22.3) | 0.001*               | 0.61                    |
| **Leg Length Discrepancy (cm)** | 0.19 (0, 0.50) | 0.26 (0, 0.50)     |                      |                         |
| **Q-Angle (°)**              | 10 (8, 13)    | 10.5 (10, 14)      | 0.92                 | 0.14                    |
| **Primary Running Sport**    | Cross-Country: N=4 Track: N=7 Long-Distance Running: N=8 | Cross-Country: N=23 Track: N=23 Long-Distance Running: N=7 | <0.001* | 0.38 |
| **RRI History**              | Ankle Sprains: N=15 Shin Splints: N=4 Stress Fractures: N=4 Plantar Fasciitis: N=3 | Ankle Sprains: N=16 Shin Splints: N=12 Stress Fractures: N=9 Plantar Fasciitis: N=0 | 0.67 |             |

Abbreviations: IQR, interquartile range; BMI, body mass index; Q-angle, quadriceps angle.
*Signifies statistically significant difference at p<0.05

beyond weekly mileage, as distance often overlooks the quality and time under tension associated with an individual run. However, previous studies comparing young and middle-aged adult runners have identified that older age compounded with higher weekly mileage resulted in altered lower extremity joint kinetics. There is also limited evidence to suggest that higher weekly mileage is a risk factor for RRIIs among male adolescent runners during pre-season training. These past associations suggest there may be a benefit to assessing weekly mileage in relationship to RRI development across age groups; however, the present findings do not support that training time and strenuous exercise frequency differ across age groups or between those with a history of RRIIs and those without.

Adult runners in this sample were more likely to include resistance training into their exercise plans. Skeletal muscle mass peaks between 20 to 40 years of age and then gradually declines, emphasizing the importance of incorporating early strengthening to capitalize on the body’s neuromuscular potential. While there was not an association between strength training and RRI, there are additional known benefits of incorporating strength training beyond the context of injury development. Strengthening has been shown to improve running economy beyond other forms of cross-training in adult populations. Additionally, resistance training leads to muscle tissue remodeling to improve strength and load capacity contributing to performance. The present findings that adolescents less frequently incorporate strengthening into their training regimens underscore the need to educate adolescent runners on the known physiological benefits of resistance training.

**WELLNESS MEASURES**

Intentional weight-loss to improve athletic performance was more common among adult runners than adolescent runners. This outcome was anticipated given that metabolism declines with age, exemplified in the included participants’ BMI characteristics. Adolescents are inherently involved in more structured activities through physical ed-
Table 2. Comparison of adult and adolescent runners with and without running-related injuries.

| Variable                              | Adult Runners | Adolescent Runners | p-value (age groups) | p-value (injury status) |
|---------------------------------------|---------------|--------------------|----------------------|-------------------------|
| Total Hours of Running Per Week (hours) | 9.6 ± 8.8     | 11.1 ± 9.5        | 0.68                 | 0.07                    |
| Strenuous Exercise Frequency (times/week) | 3.2 ± 2.6     | 3.2 ± 2.2         | 0.28                 | 0.76                    |
| Inclusion of Weight Training          | Yes: 76%      | Yes: 69%          | Yes: 37%             | Yes: 63%                |
| Hours of Weekday Sleep (hours)        | 7.5 ± 1.1     | 7.6 ± 1.0         | 0.23                 | 0.53                    |
| Intentional Weight-Loss              | Yes: 31%      | Yes: 56%          | Yes: 21%             | <0.001*                 |
| Dorsiflexion ROM (°)                 | -0.4 ± 9.9    | 2.2 ± 10.1        | -0.38 ± 9.9          | 0.25                    |
| Hip Abduction Strength (Nm/kg)       | 118 ± 33      | 112 ± 32          | 0.28                 | 0.18                    |
| Single Leg Bridge Duration (s)       | 76.0 ± 50.0   | 58.0 ± 31.0       | 0.22                 | 0.01*                   |
| FMS™ Composite Score                 | 14 ± 3        | 11 ± 3            | 0.02*                | 0.01*                   |

Abbreviations: RRI, running-related injury; ROM, range of motion; FMS™, Functional Movement Screen™.
*signifies statistically significant difference at p<0.05.

ucation programs in schools designed to combat adolescent weight gain which reduces the need to engage in intentional weight loss behaviors. Adolescents additionally require increased caloric intake to support adequate growth and maturation. However, athletes that reported intentional weight-loss behaviors were more likely to report a history of RRI regardless of age. Disordered eating and caloric restriction associated with RED-S for male and female athletes alike have been identified as independent risk factors for bone stress injuries. Bone mineral density is lowest prior to peak growth velocity and steadily declines with age, especially with insufficient nutrition. Sufficient dietary intake is essential for neuromuscular recovery from exercise and, as such, restricted fueling associated with intentional weight-loss strategies has important implications for risk of developing RRI.

FUTURE DIRECTIONS
The current assessment identified key age-related changes associated with personal and environmental factors, yet this study found that age groups were similar in terms of risk factors for developing RRI. While this hypothesis-generating study is an important preliminary step to expounding differences between adolescent and adult runners, future work should focus on additional running-specific factors as they compare across age groups and risk of RRI. Furthermore, prospective studies in larger samples including other prevalent RRI, such as PFP, are warranted. There is a robust body of literature exploring the effects of aging on running biomechanical characteristics. While previous work has found age-related biomechanical changes among middle-aged and master’s level runners (ages 65+) compared to younger adults, it is necessary to expand these examinations across the age spectrum.

LIMITATIONS
As this was a cross-sectional study, causation was not able to be established. This adult running sample was relatively small and consisted of younger adult runners, limiting extrapolation to the greater adult running community. This population of runners self-reported only select RRI, thus, our findings may not necessarily translate to other RRI diagnoses. Finally, this sample was predominately white and consisted of runners undergoing an injury prevention evaluation in a small geographic area, and as such the findings should be interpreted in the context of these limitations.
CONCLUSION

Intentional weight-loss for the purposes of improving athletic performance and lower FMS™ scores were each associated with a history of running related injury for both adult and adolescent runners, suggesting these risk factors are important across age groups. As such, these factors may represent targets for the prevention of adult and adolescent RRIs.

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CONFLICTS OF INTEREST

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