DeJong Lempke AF, Collins SE, Whitney KE, D'Hemecourt PA, Meehan WP. A Comparison of Factors Associated with Running-Related Injuries between Adult and Adolescent Runners. *IJSPT*. 2022;17(6):1033-1042.

Original Research

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

Alexandra F. DeJong Lempke[1] [a], Sara E. Collins[2], Kristin E. Whitney[3], Pierre A. D'Hemecourt[3], William P. Meehan III[3]

[1] School of Kinesiology, University of Michigan; Micheli Center for Sports Injury Prevention; Division of Sports Medicine, Department of Orthopedics, Boston Children's Hospital, [2] Micheli Center for Sports Injury Prevention; Division of Sports Medicine, Department of Orthopedics, Boston Children's Hospital, [3] Division of Sports Medicine, Department of Orthopedics, Boston Children's Hospital; Harvard Medical School

Keywords: youth, physical assessments, strength, functional movement screen, muscle endurance

https://doi.org/10.26603/001c.38045

International Journal of Sports Physical Therapy

Vol. 17, Issue 6, 2022

Background

There are multiple personal and environmental factors that influence the risk of developing running-related injuries (RRIs). 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 RRIs.

Study Design

Cross-sectional study.

Methods

Questionnaire responses and clinical assessment data were extracted from 38 adult runners (F: 25, M: 13; median age: 23 [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 RRIs 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 RRIs were more likely to report intentional weight-loss compared to uninjured runners (% difference: 21.3; p=0.02) and had shorter single leg bridge durations than those without RRIs (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

a **Corresponding author:**
Alexandra F. DeJong Lempke
SKB 1235, 830 N University Ave, Ann Arbor, MI, USA, 48109
Email: alempke@umich.edu

for the prevention of RRIs for adult and adolescent runners, given the association with history of RRIs.

Level of Evidence

3

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.[1–3] 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,[1,15,16] 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.[6,21,22] 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.[1,3,24,25] 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 stressors.[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 2013 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,[21,22,32,33] dorsiflexion range of motion,[18,34] single leg bridge duration (in seconds), and the FMS™ screen composite score.[20,35] Handheld goniometers and dynamometers were used to conduct physical assessments using standard clinical methods.[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]: -1.3 [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.[35] However, physically active adolescents have better FMS™ scores than physically inactive adolescents, attributed to improved muscular coordination through early sport participation.[38] Furthermore, studies show that tactical athletes with FMS™ scores less than 14 are at increased risk of sustaining musculoskeletal injuries.[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 dorsiflexion ROM measures. Previous studies present conflicting findings on lower extremity strength measures in relationship to injury development.[21,22,39] The most consistent evidence indicates that gluteal muscle weakness is associated with patellofemoral pain (PFP)[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.[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.[43]

TRAINING FACTORS

Running training volume and strenuous exercise frequency as a proxy for intensity were similar across age groups

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)
	Uninjured N=13 (Median [IQR])	RRI N=25 (Median [IQR])	Uninjured N=53 (Median [IQR])	RRI N=38 (Median [IQR])		
Gender	F: 9, M:4	F: 16, M:9	F: 29, M: 24	F: 27, M:11	0.33	0.72
Age (years)	24 (21, 43)	21 (18, 33)	15 (13, 15)	15 (14, 16)	<0.001*	0.13
Race	White (N=11) Black (N=1) Prefer not to answer (N=1)	White (N=23) Black (N=1) Asian (N=1)	White (N=46) Black (N=2) Asian (N=3) Native Hawaiian or Other Pacific Islander (N=1) Prefer not to answer (N=1)	White (N=36) Black (N=1) Prefer not to answer (N=1)	0.89	0.32
BMI (kg/m^2)	21.7 (19.9, 24.8)	23.8 (22.5, 26.0)	20.0 (18.3, 22.3)	19.8 (18.6, 21.6)	<0.001*	0.61
Leg Length Discre-pancy (cm)	0.19 (0, 0.50)	0.26 (0, 0.50)	0.26 (0, 0.50)	0.28 (0, 0.50)	0.84	0.39
Q-Angle (°)	10 (8, 13)	11 (10, 14)	10.5 (10, 14)	10.5 (9, 12)	0.92	0.14
Primary Running Sport	Cross-Country: N=1 Track: N=4 Long-Distance Running: N= 8	Cross-Country: N=6 Track: N=7 Long-Distance Running: N=12	Cross-Country: N=23 Track: N= 23 Long-Distance Running: N=7	Cross-Country: N=15 Track: N=22 Long-Distance Running: N=1	<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

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 beyond weekly mileage, as distance often overlooks the quality and time under tension associated with an individual run.[44] 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.[45] There is also limited evidence to suggest that higher weekly mileage is a risk factor for RRIs among male adolescent runners during pre-season training.[1] 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 RRIs 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.[46] 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.[47] Additionally, resistance training leads to muscle tissue remodeling to improve strength and load capacity contributing to performance.[47] 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.

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)	p-value (age groups* injury status)
	Uninjured (N=13)	RRI (N=25)	Uninjured (N=53)	RRI (N=38)			
Total Hours of Running Per Week (hours)	9.6 ± 8.8	11.1 9.5	9.6 ± 8.8	13.3 ± 10.8	0.68	0.07	0.19
Strenuous Exercise Frequency (times/week)	3.2 ± 2.6	3.2 ± 2.2	2.8 ± 2.2	3.2 ± 2.6	0.28	0.76	0.40
Inclusion of Weight Training	Yes: 76% No: 24%	Yes: 69% No: 31%	Yes: 55% No: 45%	Yes: 37% No: 63%	0.01*	0.17	0.61
Hours of Weekday Sleep (hours)	7.5 ± 1.1	7.6 ±1.0	7.8 ± 1.1	7.5 ± 1.1	0.23	0.53	0.57
Intentional Weight-Loss	Yes: 31% No: 69%	Yes: 56% No: 44%	Yes: 9% No: 91%	Yes: 21% No: 79%	<0.001*	0.02*	0.96
Dorsiflexion ROM (°)	-0.4 ± 9.9	2.2 ± 10.1	1.61 ± 9.7	-0.38 ± 9.9	0.25	0.26	0.51
Hip Abduction Strength (Nm/kg)	118 ± 33	112 ± 32	120 ± 30	112 ± 28	0.28	0.18	0.45
Single Leg Bridge Duration (s)	76.0 ± 50.0	58.0 ± 31.0	68.0 ± 39.6	57.7 ± 30.5	0.22	0.01*	0.28
FMS™ Composite Score	14 ± 3	11 ± 3	14 ± 3	13 ± 3	0.02*	0.01*	0.21

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

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.[48] Adolescents are inherently involved in more structured activities through physical education programs in schools designed to combat adolescent weight gain which reduces the need to engage in intentional weight loss behaviors.[49] Adolescents additionally require increased caloric intake to support adequate growth and maturation.[50] However, athletes that reported intentional weight-loss behaviors were more likely to report a history of RRIs 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.[6,23,51] Bone mineral density is lowest prior to peak growth velocity[26] and steadily declines with age, especially with insufficient nutrition.[52] Sufficient dietary intake is essential for neuromuscular recovery from exercise,[53,54] and, as such, restricted fueling associating with intentional weight-loss strategies has important implications for risk of developing RRIs.

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 RRIs. 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 RRIs. Furthermore, prospective studies in larger samples including other prevalent RRIs, 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,[45,55,56] 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 RRIs, 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.

FUNDING SOURCES

None.

ACKNOWLEDGEMENTS

We would like to thank Dr. Adam Tenforde for providing feedback and input during manuscript preparation.

CONFLICTS OF INTEREST

Dr. Meehan receives royalties from 1) ABC-Clio publishing for the sale of his books, *Kids, Sports, and Concussion: A guide for coaches and parents,* and *Concussions;* 2) Springer International for the book *Head and Neck Injuries in Young Athlete* and 3) Wolters Kluwer for working as an author for *UpToDate*. His research is funded, in part, by philanthropic support from the National Hockey League Alumni Association through the Corey C. Griffin Pro-Am Tournament and a grant from the National Football League. Dr. DeJong Lempke is an Associated Personnel with Boston Children's Hospital, and continues to collaborate on studies at this institution. She has pending grant funding from VALD Performance for a separate project.

Submitted: December 30, 2021 CDT, Accepted: June 27, 2022 CDT

REFERENCES

1. Rauh MJ. Summer training factors and risk of musculoskeletal injury among high school cross-country runners. *J Orthop Sports Phys Ther*. 2014;44(10):793-804. doi:10.2519/jospt.2014.5378

2. Rauh MJ, Koepsell TD, Rivara FP, Margherita AJ, Rice SG. Epidemiology of musculoskeletal Injuries among high school cross-country runners. *Am J Epidemiol*. 2006;163(2):151-159. doi:10.1093/aje/kwj022

3. Fredette A, Roy JS, Perreault K, Dupuis F, Napier C, Esculier JF. The association between running injuries and training parameters: A systematic review. *J Athl Train*. Published online September 3, 2021. doi:10.4085/1062-6050-0195.21

4. Yamato TP, Saragiotto BT, Lopes AD. A consensus definition of running-related injury in recreational runners: a modified delphi approach. *J Orthop Sports Phys Ther*. 2015;45(5):375-380. doi:10.2519/jospt.2015.5741

5. Marshall AN, McLeod TCV, Lam KC. Characteristics of injuries occurring during cross- country: a report from the athletic training practice-based research network. *J Athl Train*. 2020;55(12):1230-1238. doi:10.4085/1062-6050-541-19

6. Krabak BJ, Roberts WO, Tenforde AS, et al. Youth running consensus statement: minimising risk of injury and illness in youth runners. *Br J Sports Med*. 2021;55(6):305-318. doi:10.1136/bjsports-2020-102518

7. Hulme A, Nielsen RO, Timpka T, Verhagen E, Finch C. Risk and protective factors for middle- and long-distance running-related injury. *Sports Med*. 2017;47(5):869-886. doi:10.1007/s40279-016-0636-4

8. Hespanhol Junior LC, Pillay JD, van Mechelen W, Verhagen E. Meta-analyses of the effects of habitual running on indices of health in physically inactive adults. *Sports Med*. 2015;45(10):1455-1468. doi:10.1007/s40279-015-0359-y

9. Kohl HW III, Craig CL, Lambert EV, et al. The pandemic of physical inactivity: global action for public health. *Lancet*. 2012;380(9838):294-305. doi:10.1016/s0140-6736(12)60898-8

10. Chan CS, Grossman HY. Psychological effects of running loss on consistent runners. *Percept Mot Skills*. 1988;66(3):875-883. doi:10.2466/pms.1988.66.3.875

11. Kalkhoven JT, Watsford ML, Impellizzeri FM. A conceptual model and detailed framework for stress-related, strain-related, and overuse athletic injury. *J Sci Med Sport*. 2020;23(8):726-734. doi:10.1016/j.jsams.2020.02.002

12. Kalkhoven JT, Watsford ML, Coutts AJ, Edwards WB, Impellizzeri FM. Training load and injury: causal pathways and future directions. *Sports Med*. 2021;51(6):1137-1150. doi:10.1007/s40279-020-01413-6

13. Bertelsen ML, Hulme A, Petersen J, et al. A framework for the etiology of running-related injuries. *Scand J Med Sci Sports*. 2017;27(11):1170-1180. doi:10.1111/sms.12883

14. Nilsson J, Thorstensson A. Ground reaction forces at different speeds of human walking and running. *Acta Physiol Scand*. 1989;136(2):217-227. doi:10.1111/j.1748-1716.1989.tb08655.x

15. Almeida GPL, Ana Paula de Moura Campos Carvalho e Silva, França FJR, Magalhães MO, Burke TN, Marques AP. Q-angle in patellofemoral pain: relationship with dynamic knee valgus, hip abductor torque, pain and function. *Rev Bras Orto (English Edition)*. 2016;51(2):181-186. doi:10.1016/j.rboe.2016.01.010

16. Lun V, Meeuwisse WH, Stergiou P, Stefanyshyn D. Relation between running injury and static lower limb alignment in recreational runners. *Br J Sports Med*. 2004;38(5):576-580. doi:10.1136/bjsm.2003.005488

17. Becker J, Nakajima M, Wu WFW. Factors contributing to medial tibial stress syndrome in runners: a prospective study. *Med Sci Sports Exerc*. 2018;50(10):2092-2100. doi:10.1249/mss.0000000000001674

18. Winters M, Eskes M, Weir A, Moen MH, Backx FJG, Bakker EWP. Treatment of medial tibial stress syndrome: a systematic review. *Sports Med*. 2013;43(12):1315-1333. doi:10.1007/s40279-013-0087-0

19. Bock C, Orr RM. Use of the functional movement screen in a tactical population: a review. *J Mil Veterans Health*. 2015;23(2):10.

20. Davis JD, Orr R, Knapik JJ, Harris D. Functional movement screen (FMSTM) scores and demographics of US army pre-ranger candidates. *Mil Med*. 2020;185(5-6):e788-e794. doi:10.1093/milmed/usz373

21. Almeida GPL, Carvalho e Silva AP de MC, França FJR, Magalhães MO, Burke TN, Marques AP. Does anterior knee pain severity and function relate to the frontal plane projection angle and trunk and hip strength in women with patellofemoral pain? *J Bodyw Mov Ther*. 2015;19(3):558-564. doi:10.1016/j.jbmt.2015.01.004

22. Koldenhoven RM, Virostek A, DeJong AF, Higgins M, Hertel J. Increased contact time and strength deficits in runners with exercise-related lower leg pain. *J Athl Train*. 2020;55(12):1247-1254. doi:10.4085/1062-6050-0514.19

23. Mountjoy M, Sundgot-Borgen JK, Burke LM, et al. IOC consensus statement on relative energy deficiency in sport (RED-S): 2018 update. *Br J Sports Med*. 2018;52(11):687-697. doi:10.1136/bjsports-2018-099193

24. Post EG, Trigsted SM, Riekena JW, et al. The association of sport specialization and training volume with injury history in youth athletes. *Am J Sports Med*. 2017;45(6):1405-1412. doi:10.1177/0363546517690848

25. Edwards WB, Taylor D, Rudolphi TJ, Gillette JC, Derrick TR. Effects of stride length and running mileage on a probabilistic stress fracture model. *Med Sci Sports Exerc*. 2009;41(12):2177-2184. doi:10.1249/mss.0b013e3181a984c4

26. Faulkner RA, Davison KS, Bailey DA, Mirwald RL, Baxter-Jones AD. Size-corrected BMD decreases during peak linear growth: implications for fracture incidence during adolescence. *J Bone Miner Res*. 2006;21(12):1864-1870. doi:10.1359/jbmr.060907

27. Krabak BJ, Snitily B, Milani CJE. Running injuries during adolescence and childhood. *Phys Med Rehabil Clin N Am*. 2016;27(1):179-202. doi:10.1016/j.pmr.2015.08.010

28. Erwin AM, Bashore L. Subjective sleep measures in children: self-report. *Front Pediatr*. 2017;5:22. doi:10.3389/fped.2017.00022

29. Cade J, Thompson R, Burley V, Warm D. Development, validation and utilisation of food-frequency questionnaires – a review. *Public Health Nutr*. 2002;5(4):567-587. doi:10.1079/phn2001318

30. Rauh MJ, Koepsell TD, Rivara FP, Rice SG, Margherita AJ. Quadriceps angle and risk of injury among high school cross-country runners. *J Orthop Sports Phys Ther*. 2007;37(12):725-733. doi:10.2519/jospt.2007.2453

31. Rauh MJ. Leg-length inequality and running-related injury among high school runners. *Intl J Sports Phys Ther*. 2018;13(4):643-651. doi:10.26603/ijspt20180643

32. DeJong AF, Koldenhoven RM, Hertel J. Proximal adaptations in chronic ankle instability: systematic review and meta-analysis. *Med Sci Sports Exerc*. 2020;52(7):1563-1575. doi:10.1249/mss.0000000000002282

33. Ireland ML, Willson JD, Ballantyne BT, Davis IM. Hip strength in females with and without patellofemoral pain. *J Orthop Sports Phys Ther*. 2003;33(11):671-676. doi:10.2519/jospt.2003.33.11.671

34. Crosbie J, Green T, Refshauge K. Effects of reduced ankle dorsiflexion following lateral ligament sprain on temporal and spatial gait parameters. *Gait Posture*. 1999;9(3):167-172. doi:10.1016/s0966-6362(99)00010-7

35. Mitchell UH, Johnson AW, Vehrs PR, Feland JB, Hilton SC. Performance on the functional movement screen in older active adults. *J Sport Health Sci*. 2016;5(1):119-125. doi:10.1016/j.jshs.2015.04.006

36. Norkin CC, White DJ. *Measurement of Joint Motion: A Guide to Goniometry*. F.A. Davis; 2009.

37. Kelln BM, McKeon PO, Gontkof LM, Hertel J. Hand-held dynamometry: reliability of lower extremity muscle testing in healthy, physically active, young adults. *J Sport Rehabil*. 2008;17(2):160-170. doi:10.1123/jsr.17.2.160

38. Lubans DR, Morgan PJ, Cliff DP, Barnett LM, Okely AD. Fundamental movement skills in children and adolescents: review of associated health benefits. *Sports Med*. 2010;40(12):1019-1035. doi:10.2165/11536850-000000000-00000

39. Torp DM, Donovan L, Gribble PA, Thomas AC, Bazett-Jones DM, Beard MQ. No baseline strength differences between female recreational runners who developed an injury and injury free runners during a 16-week formalized training program. *Phys Ther Sport*. 2018;34:1-7. doi:10.1016/j.ptsp.2018.08.001

40. Bolgla LA, Malone TR, Umberger BR, Uhl TL. Comparison of hip and knee strength and neuromuscular activity in subjects with and without patellofemoral pain syndrome. *Int J Sports Phys Ther*. 2011;6(4):285.

41. Holden S, Boreham C, Doherty C, Delahunt E. Two-dimensional knee valgus displacement as a predictor of patellofemoral pain in adolescent females. *Scand J Med Sci Sports*. 2017;27(2):188-194. doi:10.1111/sms.12633

42. Van Cant J, Pitance L, Feipel V. Hip abductor, trunk extensor and ankle plantar flexor endurance in females with and without patellofemoral pain. *J Back Musculoskelet Rehabil*. 2017;30(2):299-307. doi:10.3233/bmr-150505

43. Kim D, Unger J, Lanovaz JL, Oates AR. The relationship of anticipatory gluteus medius activity to pelvic and knee stability in the transition to single-leg stance. *PM R*. 2016;8(2):138-144. doi:10.1016/j.pmrj.2015.06.005

44. Paquette MR, Napier C, Willy RW, Stellingwerff T. Moving beyond weekly "distance": optimizing quantification of training load in runners. *J Orthop Sports Phys Ther*. 2020;50(10):564-569. doi:10.2519/jospt.2020.9533

45. Paquette MR, Powell DW, DeVita P. Age and training volume influence joint kinetics during running. *Scand J Med Sci Sports*. 2021;31(2):380-387. doi:10.1111/sms.13857

46. Yamada Y. Muscle mass, quality, and composition changes during atrophy and sarcopenia. In: Xiao J, ed. *Muscle Atrophy*. Advances in Experimental Medicine and Biology. Springer; 2018:47-72. doi:10.1007/978-981-13-1435-3_3

47. Blagrove RC, Howatson G, Hayes PR. Effects of strength training on the physiological determinants of middle- and long-distance running performance: a systematic review. *Sports Med*. 2018;48(5):1117-1149. doi:10.1007/s40279-017-0835-7

48. Jura M, Kozak LP. Obesity and related consequences to ageing. *Age (Dordr)*. 2016;38(1):23. doi:10.1007/s11357-016-9884-3

49. Hills AP, Dengel DR, Lubans DR. Supporting public health priorities: recommendations for physical education and physical activity promotion in schools. *Prog Cardiovasc Dis*. 2015;57(4):368-374. doi:10.1016/j.pcad.2014.09.010

50. Dietary Guidelines for Americans, 2020-2025. :164.

51. Tenforde AS, DeLuca S, Wu AC, et al. Prevalence and factors associated with bone stress injury in middle school runners. *PM R*. Published online September 30, 2021. doi:10.1002/pmrj.12673

52. Aspray TJ, Hill TR. Osteoporosis and the ageing skeleton. *Subcell Biochem*. 2019;91:453-476. doi:10.1007/978-981-13-3681-2_16

53. Lee EC, Fragala MS, Kavouras SA, Queen RM, Pryor JL, Casa DJ. Biomarkers in sports and exercise: tracking health, performance, and recovery in athletes. *J Strength Cond Res*. 2017;31(10):2920-2937. doi:10.1519/jsc.0000000000002122

54. Valentine RJ, Saunders MJ, Todd MK, St. Laurent TG. Influence of carbohydrate-protein beverage on cycling endurance and indices of muscle disruption. *Int J Sport Nutr Exerc Metab*. 2008;18(4):363-378. doi:10.1123/ijsnem.18.4.363

55. Barnard JR, Grimditch GK, Wilmore JH. Physiological characteristics of sprint and endurance Masters runners. *Med Sci Sports*. 1979;11(2):167-171.

56. Willy RW, Paquette MR. The physiology and biomechanics of the master runner. *Sports Med Arthrosc Rev*. 2019;27(1):15-21. doi:10.1097/jsa.0000000000000212

SUPPLEMENTARY MATERIALS

Appendix 1

Download: https://ijspt.scholasticahq.com/article/38045-a-comparison-of-factors-associated-with-running-related-injuries-between-adult-and-adolescent-runners/attachment/98604.docx