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Normative Measures of Hip Strength and Relation to Previous Injury in Collegiate Cross-Country Runners

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Context: Running-related injury occurs frequently in collegiate cross-country runners. Hip strength is one factor that may be important in the rehabilitation and training of cross-country runners. However, no normative values exist to inform these strategies.

Objective: To establish normative values for hip-abduction and external-rotation isometric strength in collegiate cross-country runners and explore the association between strength and previous injury.

Design: Mixed methods using descriptive epidemiology and retrospective cross-sectional designs.

Setting: University laboratory.

Patients or Other Participants: Eighty-two National Collegiate Athletic Association Division III cross-country runners (38 males, 44 females).

Main Outcome Measure(s): Isometric hip strength and reported injury.

Results: Males demonstrated greater absolute hip strength than females. Measures of hip strength were not different between sexes when normalized to height and mass. Hip-abduction asymmetry was associated with a previous injury in males. A combination of at least 1 leg with hip-abduction weakness and bilateral external-rotation weakness was associated with a previous injury in females.

Conclusions: Knowledge of normative values of hip strength may help inform rehabilitation strategies in collegiate cross-country runners. Males and females may demonstrate different strength profiles after running-related injury.

Key Words: athletic injuries, sex differences

Key Points

- Male and female Division III collegiate cross-country runners demonstrated similar normalized values of hip strength (seated external rotation = 2.88–3.36 N·m/kg, abduction = 2.85–3.35 N·m/kg, prone ER = 2.81–3.69 N·m/kg).
- Normative strength values may help inform therapeutic and training strategies by providing a referent standard.
- Previously injured male and female Division III collegiate cross-country runners may differ in hip strength; males showed asymmetry in abduction and females demonstrated weakness in abduction and external rotation.

To promote safe participation in sport, the ability to identify both nonmodifiable and modifiable risk factors for injury may be critical to our understanding each athlete's personal risk profile.[1] Cross-country running is a popular sport with nearly 30 000 participants in the 2018–2019 National Collegiate Athletic Association (NCAA) season.[2] However, when monitored for more than 1 year, 77.4% of cross-country runners reported time-loss injuries, and the lifetime injury rate has been estimated at 94.4%.[3] To address this relatively high injury rate, several authors have attempted to identify risk factors associated with running-related injury (RRI).[4–6] The cumulative evidence for specific risk factors of RRI depends on the individual runner's characteristics, such as age, sex, experience, weekly running mileage, training intensity, use of shoe inserts, and level of competition.[3–7]

To help guide injury-prevention strategies, a recent framework has been proposed.[8] Despite the multifactorial nature of RRIs, Bertelsen et al[8] suggested that 4 factors may contribute to the development of RRIs: the "structure-specific load capacity" of an individual runner entering a running session, the "structure-specific cumulative load" per running session, the "reduction in structure-specific load" during a running session, and "exceeding the structure-specific capacity." With regard to the structure-specific load capacity, several components have been stated to contribute to a runner's load capacity, such as age, sex, sleep, diet, training history, genetics, medication use, and participation in other sports.[8] Each of these variables may affect the health and resiliency of tissue to accommodate loads. Some authors[1,9,10] have suggested that strength may be an important factor that contributes to an athlete's overall load capacity. The strength of the hip musculature has been of particular focus due to its contributions to modify and stabilize the movement of the trunk, hip, and knee.[11–14] Indeed in a clinical review, Ferber et al[15] commented that increasing evidence points to the strength of the hip abductors and external rotators and their ability to stabilize the hip joint during running as factors for RRIs.

Despite the potential importance of proximal stability from the hip being acknowledged as a factor in RRI, consensus is lacking as to the influence of hip strength as a risk factor for RRI.[16–19] The cumulative hip evidence appears to suggest that the reported discrepancies may be due to differences in study designs[20] or the types of injuries examined.[21] A notable methodologic feature of these previous investigations is that they were comparative

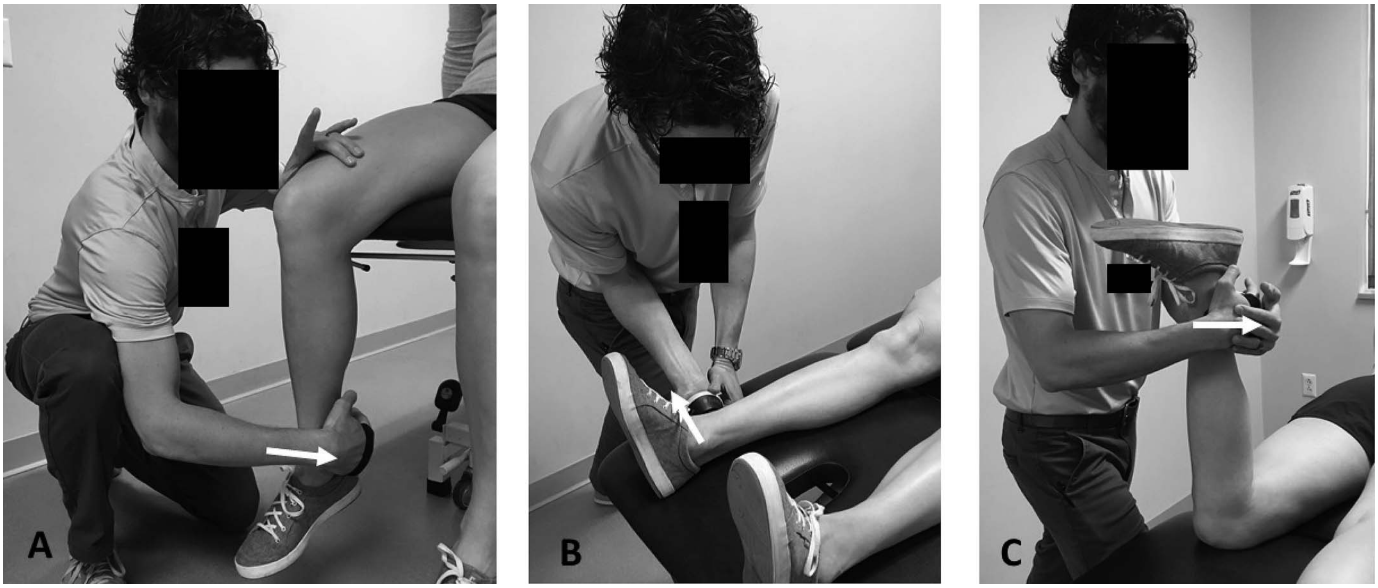

Figure. Testing positions and stabilization of the dynamometer during strength measurements. A, Seated hip external rotation. B, Supine hip abduction. C, Prone hip external rotation.

studies of differences in strength measures between injured and uninjured groups.

To better determine if these hip-related strength measures are important, we need to understand what constitutes normative strength in order to identify if an individual is "weak." To our knowledge, only a single group[22] has investigated normative hip strength in runners, and they focused on hip-abduction strength. Further, these authors studied novice runners to develop a predictive equation of eccentric hip-abduction strength based on age and sex. Thus, to help understand the role hip strength may have in RRI and inform performance and rehabilitative strategies, we must further characterize normative hip-strength measures and normative values for other samples of runners. The purpose of our study was to provide normative measures for hip-abduction and external-rotation (ER) strength in collegiate cross-country runners. A secondary purpose was to explore if runners identified as weak predicted those who reported a previous RRI.

METHODS

In this mixed-methods study, we used a descriptive epidemiologic design to identify normative measures of isometric hip-abduction, seated ER, and prone ER strength. A retrospective cross-sectional design was then applied to investigate if classification based on normative strength measures (identified as *weak* by a normalized strength score $<$95% CI) and limb asymmetry (side-to-side difference $>$10%) predicted those runners who reported a previous injury.

Participants

Data were collected on incoming athletes planning to participate in an NCAA Division III cross-country season. Annually over 4 competitive years, all new members of the university's men's and women's cross-country teams were invited to participate. Athletes who had participated in the study the previous year did not complete a second round of data collection. Any athlete with a current injury or health condition that limited running was excluded. A total of 82 runners (38 males, 44 females) participated in this study. Institutional review board approval was obtained, and all participants provided informed consent.

Procedures

All participants completed running history forms that cataloged their previous injuries and training patterns. The definition of *injury* was similar to that of Kerr et al[23]: occurred as a result of participation in a planned practice or competition, required attention from a health care professional, and resulted in restriction of running for $\geq$1 day.

Maximum isometric hip-abduction and hip-ER strength were measured by a licensed physical therapist using a handheld dynamometer (microFET2, Hoggan Scientific, LLC). For hip abduction, the athlete was placed in supine position on the examining table with the hips in neutral rotation and 0° of hip extension and the knees in full extension. After the examiner gave an oral description of the testing procedures, the dynamometer was stabilized against the athlete's lower leg just above the lateral malleolus. Using visual observation, the examiner ensured that no compensatory rotational motion occurred at the hip. Hip ER was measured in both the prone and seated positions with the knee flexed to 90° and the dynamometer placed against the athlete's lower leg just above the medial malleolus. The athletes performed at least 1 practice trial to ensure that they understood the desired motion. The testing sequence was standardized for efficient transitioning between positions such that seated ER was tested first, followed by supine hip abduction, and then prone ER (Figure). Three trials were completed on both legs for each position with instructions to apply maximum effort for 5 seconds against the dynamometer held in place by the therapist's hand. No external supports were provided for stabilization, aside from confirming that the hips stayed flat against the table. This method of measuring isometric hip strength has demonstrated strong relative and absolute reliability (intraclass correlation values = 0.95–0.99, standard error of measurement <5 N) for each motion tested.[24]

Data Analysis

Strength Normative Data. The average of 3 trials was determined for each hip-strength assessment. Each limb was treated as independent: the right and left legs were analyzed individually. Male and female measures were reported separately. Absolute scores were recorded and normalized scores were calculated by multiplying the absolute score by the athlete's height and then dividing by the athlete's mass.[17] Height and mass were self-reported as part of the running history form. Means and 95% CIs were calculated for each strength assessment.

Strength Asymmetry Data. Side-to-side comparisons of each hip-strength assessment were completed for each athlete. A limb symmetry index was calculated by dividing the strength of the left leg by the strength of the right leg and multiplying by 100. The absolute value of the difference of this score from 100% was the strength asymmetry score. A score >10% indicated strength asymmetry; this was consistent with clinical recommendations applied during functional testing and screening.[25]

Injury History Data. Athletes provided a self-reported running-injury history according to the definition of injury (see Procedures). Those runners who described any previous injury to the hip, knee, ankle, thigh, leg, or foot were categorized as *previously injured*.

Statistical Analysis

We conducted Student *t* tests to investigate differences between males and females in physical features (height and mass) and strength. Years of running experience and proportions of previous injuries reported were also compared between sexes. The α level was set to .05 for each test.

To assess the role of strength and its ability to accurately identify those runners who reported a previous injury, we compared each athlete's strength score with the sex-specific normative value from our sample. Athletes were categorized as having either 1 or both legs characterized as weak if the strength measure was outside the lower boundary of the 95% CI and if any strength asymmetry (>10%) was present between limbs. A categorical variable was created based on each runner's classification that indicated either *yes* or *no* to each descriptor of hip strength (ie, one leg classified weak in hip abduction: *yes* or *no*; both legs classified as weak in hip abduction: *yes* or *no*; and legs classified as displaying hip-abduction–strength asymmetry: *yes* or *no*). A stepwise binary logistic regression was then performed using these categorical variables to determine if they predicted the previous injury classification. The α level was set to .05.

RESULTS

Athlete demographics are presented in Table 1. Males were taller and heavier than females but had fewer years of running experience. Females had an 18.2% greater proportion of reported injury than males. Normative measures are provided for both absolute hip-strength measures and normalized hip-strength measures based on motion (Table 2). Males demonstrated greater absolute measures of hip strength ($P < .001$ for all motions), but no differences between sexes were observed in hip strength when normalized to height and mass for any of the motions examined (P values = .387–.529).

Table 1. Demographic Data of Study Participants

Characteristic	Males	Females	*P* Value
Height, m	1.79 ± 0.080[a]	1.65 ± 0.068	<.001
Mass, kg	67.8 ± 6.61	54.1 ± 5.62	<.001
Experience, y	5 (1–10)	6 (4–10)	.009
Injury proportion, %	56.8	75.0	Not applicable

[a] Values are reported as mean ± SD or median (range).

In females, only 13 (29.5%) runners had normative hip-strength measures in all the motions examined and 81.8% of female runners had at least 1 hip-strength asymmetry. Among males, only 11 (29.7%) runners had normative hip strength in all motions tested and 75.7% had at least 1 hip-strength asymmetry.

Logistic regression indicated that some hip-strength measures were able to predict the previous running-injury group. When male and female athletes were considered together, no measures of strength or asymmetry predicted injury status. In males, hip-abduction strength asymmetry was the sole predictor of a previous running injury ($P =$ .013), demonstrating sensitivity of 81.25% and specificity of 61.90% (Table 3). In females, weakness in hip-abduction strength of at least 1 leg ($P = .003$) and weakness in prone hip-ER strength of both legs ($P = .004$) predicted a previous running injury with sensitivity of 88.24% and specificity of 77.78% (Table 4).

DISCUSSION

The purpose of our study was to establish normative isometric hip-abduction and ER strength data in collegiate cross-country runners and explore the ability to predict a previous running injury in those classified as weak according to these normative measures. To our knowledge, we are the first to report absolute and normalized measures of hip strength for males and females in a specific subgroup of runners. These data may aid in identifying athletes' need for customized hip-strengthening programs by providing a reference standard for determining if hip-abduction and ER weakness is present.

Males and females in this study demonstrated expected differences in height, weight, and absolute strength, with males displaying larger values for all of these measures. However, when measures of hip strength were normalized to height and body mass, hip-strength differences between males and females became nonsignificant. Previous researchers[14,16,22] found that isometric hip-abduction–strength normative measures in females were less than in males. This inconsistency with the literature may be due to differences in the samples and populations examined. We sampled competitive collegiate runners, whereas Ramskov et al[22] evaluated novice runners, Niemuth et al[16] assessed recreational runners, and Leetun et al[14] examined track athletes and basketball players. This may indicate that at higher levels of competition, female runners' hip-abduction and ER strength profiles may be similar to those of males. Earlier authors[5,6] suggested that the level of competition

Table 2. Normative Hip-Strength Measures for Male and Female Collegiate Cross-Country Runners

Measurement	Mean (95% CI)		
	Seated Hip External Rotation	Hip Abduction	Prone Hip External Rotation
Males			
Absolute strength, N	127 (101, 153)[a]	127 (96.1, 158)[a]	126 (96.2, 155)[a]
Normalized strength, N · m/kg	3.36 (3.21, 4.05)	3.35 (3.17, 4.10)	3.69 (2.94, 6.93)
Females			
Absolute strength, N	94.7 (89.0, 100)[a]	93.6 (86.9, 100)[a]	92.2 (87.1, 97.3)[a]
Normalized strength N · m/kg	2.88 (2.72, 3.03)	2.85 (2.66, 3.04)	2.81 (2.67, 2.96)

[a] Indicates value was different between sexes ($P < .05$).

may be an important factor in running-injury etiology. Thus, the clinical implications may be that normative measures from a comparable sample population are preferred when assessing hip strength in runners and that normative values from athletes in other sports may not be applicable to runners.[25]

Most of our runners (approximately 70% of both males and females) had at least 1 motion measured as weak and at least 1 strength asymmetry present (males = 75.7%, females = 81.8%). All CIs and side-to-side differences were greater than the range of standard errors reported for isometric strength of the hip motions measured for both males and females. This indicates that some degree of hip weakness or strength asymmetry (or both) may be typical, even in competitive collegiate runners. Despite the high percentages of males and females showing hip weakness or strength asymmetry, the injury proportion among males and females was lower than the frequency of both weakness and asymmetry (see Table 1). This raises the question: when does weakness or asymmetry become associated with RRI for a given runner?

In light of the multifactorial nature of RRI,[8,10,26,27] weakness is likely one factor that interacts with several other components of each runner's health, structure, and running mechanics and affects the overall risk profile. As hip strength appears to have some relation to both injury and running mechanics,[20,21] understanding what constitutes "weak" hip muscles for specific running populations may help to mitigate injury risk and inform training strategies.

When we used logistic regression to predict runners with a previous injury based on sex, males with hip-abduction asymmetry had an increased likelihood of a history of running injury, whereas in females, combined hip-abduction and ER weakness was related to running-injury history. This may suggest that individual hip-strength measures of specific, or isolated, motions may not be strong indicators of injury status; rather, a combination of hip-strength measures may be more informative.

This notion is partially supported by the findings of Finnoff et al,[17] who reported that hip-strength ratios between the abductors and adductors and external and internal rotators were the strongest predictors of the development of patellofemoral pain in high school running athletes. A larger imbalance between the hip abductors and adductors had an odds ratio of 14.14, indicating a greater likelihood of those with stronger hip abductors relative to their hip adductors developing patellofemoral pain in the subsequent running season. In addition, those who displayed a greater ER:IR strength ratio had a reduced risk of developing patellofemoral pain based on an odds ratio of 0.01.

In a cross-sectional study of recreational runners, Niemuth et al[16] also found that injured runners demonstrated reduced hip-abduction and hip-flexor strength when the injured leg was compared with the uninjured leg. Further, the injured-side adductor muscles were noted to be stronger than the uninjured side. These authors concluded that strength "imbalances" across the hip may be important considerations in lower extremity overuse injuries in runners.

Different study designs may have accounted for these 2 results seemingly being in opposition to each other, where one[17] indicated that stronger abductors predicted injury and the other[16] suggested that weaker abductors might be associated with injury. Finnoff et al[17] used a prospective research design, whereas Niemuth et al[16] used a retrospective design. This discrepancy between study designs appears to be systematic across the literature relative to patellofemoral pain; changes in strength may have occurred subsequent to injury and therefore not indicate causative factors.[20]

Thus, it may be relevant to consider strength imbalances and ratios in athletes as well as compare the magnitudes of peak strength with those of other athletes at a similar competitive level. Establishing normative hip data for different levels of competition may be an important first step in these determinations. Further research is needed to determine the amount of hip weakness present, the combination of hip weakness from different motions, side-to-side asymmetry, and what type of strength assess-

Table 3. Contingency Table for Predicting Previous Running-Related Injury Status of Male Collegiate Cross-Country Runners[a]

Observed Injury?	Predicted Injury?	
	Yes	No
Yes	13	8
No	3	13

[a] Prediction of running-related injury status of male runners based on hip-abduction strength asymmetry.

Table 4. Contingency Table for Predicting Previous Running-Related Injury Status of Female Collegiate Cross-Country Runners[a]

Observed Injury?	Predicted Injury?	
	Yes	No
Yes	30	2
No	4	7

[a] Prediction of running-related injury status of females based on hip-abduction weakness in 1 leg and prone hip–external-rotation weakness in both legs as determined by values <95% CI for sex-specific normative values.

ment (ie, isometric versus isokinetic) may be most appropriate for determining the risk of RRI.

In addition, our results seem to suggest that males and females demonstrated different strength profiles as related to injury status: in males, hip-abduction asymmetry was important, and for females, hip-abduction and ER weakness were important. This may suggest that males and females displayed different responses in the hip musculature after injury, consistent with a previous meta-analysis[6] that indicated males and females may have unique biomechanical profiles relevant to RRI. To what extent these changes in strength and running mechanics are related has yet to be fully determined. Earlier authors[14,16,17] investigated hip strength and its relationship to injury among mixed-sex samples, and sex differences were apparent in running mechanics.[28–30] Future research to explore this relationship of hip strength to RRI using sex-specific designs is needed.

Several limitations of this study must be noted. First, we examined only 3 motions at the hip. These motions were selected as they influence hip adduction and internal rotation in running, which have been identified as prospective risk factors for RRI.[5,6] However, because we only assessed these 3 motions, it was not possible to evaluate antagonist:agonist ratios, which might have been useful to more fully characterize strength profiles at the hip.

Second, we tested isometric strength, whereas Ramskov et al[22] advocated that eccentric-strength assessments may be more applicable to running and Taylor-Haas et al[11] recommended isokinetic-strength assessment. Despite these results, no consensus currently exists on the ideal strength-assessment modality in runners; therefore, when comparing normative measures, the mode of strength assessment should be considered. Our testing method was rather simple, requiring no equipment except a handheld dynamometer, and could be easily implemented in clinical settings. The collection of such data allows clinicians and athletic-team staff to obtain these measures as a basis for comparison.

Next, we normalized hip-strength measures according to height and mass as opposed to leg length and mass. It is important to note that a true torque assessment about a joint requires a measure of limb length. However, we selected height and mass for ease of implementation in situations such as when athletic teams are undergoing large field-testing sessions or for screenings to reduce the number of measures recorded by team staff. This form of normalization has been used previously.[17]

Additionally, our data were collected on a very specific subpopulation of runners (NCAA Division III cross-country athletes) and, as such, may not be applicable to runners outside of the 18 to 22-year-old age range, running at a different level of competition, or training for a different race distance.

Finally, we investigated injury history. These findings do not necessarily delineate the risk for subsequent injury as a causal relationship cannot be determined from our research design. Rather, the findings may help clinicians identify how hip strength may be affected by previous injury, influence future injury risk, and help inform training and therapeutic approaches for runners.

We present normative measures of hip-abduction and ER strength (in sitting and prone positions) for male and female NCAA Division III cross-country runners that may be used by athletic trainers and sports medicine providers to identify hip weakness. The findings may assist athletic trainers and other health care providers in describing atypical strength profiles and informing therapeutic and performance efforts in collegiate cross-country runners.

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