Do Injury-Resistant Runners Have Distinct Differences in Clinical Measures Compared with Recently Injured Runners?

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ABSTRACT

DILLON, S., A. BURKE, E. F. WHYTE, S. O’CONNOR, S. GORE, and K. A. MORAN. Do Injury-Resistant Runners Have Distinct Differences in Clinical Measures Compared with Recently Injured Runners? Med. Sci. Sports Exerc., Vol. 53, No. 9, pp. 1807–1817, 2021.

Introduction: Although lower extremity muscle strength, joint motion, and functional foot alignment are commonly used, time-efficient clinical measures that have been proposed as risk factors for running-related injuries, it is unclear if these factors can distinguish injury resistance in runners. Purpose: This study compares clinical measures, with consideration of sex, between recently injured runners (3 months to 1 yr prior), those with a high level of injury resistance who have been uninjured for at least 2 yr, and never-injured runners. Methods: Averaged bilateral values and between-limb symmetry angles of lower limb isometric muscle strength, joint motion, navicular drop, and foot posture index (FPI) were assessed in a cohort of recreational runners, and their injury history was recorded. Differences in clinical measures between injury groupings were examined, with consideration of sex. Results: Of the 223 runners tested, 116 had been recently injured, 61 had been injured >2 yr ago and were deemed to have acquired reinjury resistance, and 46 were never injured. Plantarflexion was greater in both recently injured (P = 0.001) and acquired reinjury resistance runners (P = 0.001) compared with never-injured runners. Recently injured runners displayed higher hip abduction strength compared with never-injured runners (P = 0.019, η² = 0.038, small effect size). There were no statistically significant differences in the remaining measures between the injury groupings. With the exception of FPI, there was no interaction between sex and injury grouping for any of the measures. Conclusion: Commonly used clinical measures of strength, joint motion, and functional foot alignment were not superior in injury-resistant runners compared with recently injured runners, questioning their relevance in identifying future injury resistance of runners. Key Words: RUNNING INJURIES, STRENGTH, PRONATION, JOINT MOTION

Runners are subject to a high incidence of lower extremity injury of between approximately 20% to 80% (1). The pervasive biomechanical model of injury identifies excessive loading to tissues to be causative of injuries (2). Running is a cyclical movement that exposes the body to repetitive loads of up to 2.8 times body weight with each step (3). Clinical measures of muscle strength, functional foot alignment, and joint motion have been suggested to be related to loading (4,5) and, although evidence is mixed, may be related to injury itself (6–8). Furthermore, studies involving the asymmetry of these factors have demonstrated a similarly mixed relationship to injury (9–11). Imbalances in factors such as tissue strength and joint motion may be a precursor to injury. In addition, at return to sport, asymmetry in factors such as tissue strength acquired as a result of injury-induced tissue damage may persist (9), potentially causing reinjury. These clinical measures are advantageous in being time efficient, low cost, and readily available to most clinicians, making their potential use in managing running-related injuries (RRI) particularly valuable.

Because of cost and time constraints, retrospective studies are the predominant methodology in examining factors associated with RRI. One group of runners frequently studied are those who have relatively recently recovered from injury and returned to play (e.g., less than 12 months postinjury). This group is of interest because they are thought to no longer retain the acute effects of injury itself but may still maintain factors related to injury given the high risk of reinjury during this period (12). A second group of runners worth studying are those...
who have recovered from injury but have not experienced a re-
jury (e.g., >2 yr since injury). This acquired reinjury resis-
tance group may logically be less likely to retain the risk
factors associated with injury/reinjury, or at least have a re-
duced weighting. A third and final group worth examining,
and perhaps the most interesting, would be those who have
never been injured. Given the high lifetime incidence of RRI
(~92%) (13), this group would potentially have no or signifi-
cantly reduced levels of risk factors. A comparison of these
two groups may provide novel and important insight into
the three clinical-based factors possibly related to RRI: muscle
strength, functional foot alignment, and joint motion. To the
authors’ knowledge, no previous study has undertaken such
a three-way comparison for any factors related to RRI. Zifchock
and colleagues (10) examined differences in hip motion and
arch height between never-injured (n = 20) and previously in-
jured recreational runners (n = 20), reporting both to be greater
in the previously injured group. However, results of the study
should be interpreted with caution as this was a small study
and it did not take into account the possibly confounding effect
of sex, a potentially important factor given that males are re-
ported to be at an increased risk of RRI (14) and sex-specific
differences in injury risk profiles have been suggested to ex-
st (15). In addition, Zifchock et al. (10) did not examine
muscle strength as a primary factor, which may be import-
tant because of its relationship to both tissue loading
(through movement technique) and tissue integrity, whose
balance is central to the occurrence of musculoskeletal inju-
ries (2). The examination of clinical measures may provide
greater insight into the potentially distinct characteristics of
runners who have either acquired reinjury resistance or have
never been injured in comparison with those who have been re-
cently injured, and the results may inform injury prevention and
rehabilitation strategies.

This study therefore aims to examine the effect of injury sta-
tus and sex on values of strength, functional foot alignment,
and joint motion using three distinct injury status groups: those
who have recently returned from injury (injured 3 months–1 yr
previously), those who have acquired reinjury resistance
(remained uninjured for >2 yr), and those who have never
been injured (never injured). It was hypothesized that those
with a high level of injury resistance (i.e., never-injured run-
ers and those who had not been injured for over 2 yr) may
have advantageous clinical measures of strength, functional
foot alignment, and joint motion compared with a recently
injured group. A secondary aim was to investigate whether
asymmetry values would be distinctive among groups, with
injury-resistant runners hypothesized to have less asymmetry.
It was also hypothesized that sex-specific differences may ex-
ist between groups.

METHODS

Participants. As part of a more extensive study, male and
female recreational runners from Dublin and its surrounding
areas were recruited between the period of January and
August 2018. Recreational runners between 18 and 65 yr with
no injury within the last 3 months were included in this study
(14). Three participant groups were later constructed: those in-
jured 3–12 months prior (“recently injured”), those whose
most recent injury was over 2 yr ago (“acquired reinjury resis-
tance”), and those who had never been injured (“never in-
jured”). A history of injury in the preceding year is cited as a
main risk factor for future injury (12). Therefore, it was hy-
pothesized that participants with a longer duration since injury
would be less likely to retain the effects of injury and may
demonstrate clinical factors that can contribute to their “injury
resistance.” The exclusion of participants injured 1–2 yr previ-
ously was done to ensure clear demarcation between “recently
injured” and “acquired reinjury resistance” groups. To limit
the effects of injuries related to nonrunning activities, partici-
pants were excluded if they participated in team, contact, or
high-impact sports. A recreational runner was defined as a per-
son who runs a minimum of 10 km·wk⁻¹ for at least 6 months
before their inclusion in the study (12).

Sample size. Sample size was determined a priori (alpha
probability = 0.05, with a power of 1 − β = 0.80, effect size
f = 0.25) for a two-way ANOVA using a power analysis pro-
gram, G*Power 3.1.9.7 (16). Because of the presence of mul-
tiple variables and difficulty ascertaining which variable to
base the power analysis on, the effect size was determined
using a standardized medium effect size value (small = 0.1,
medium = 0.25, large = 0.40) (16). A total sample size of
158 was reached.

Ethical approval. Ethical approval was sought from and
granted by the Dublin City University Ethics Committee
(DCUREC/2017/186).

Procedures. Eligible participants completed an informed
consent form to partake in this study and then completed an
online survey regarding their injury and training history. Par-
ticipants then attended a single baseline testing session in
which isometric strength, joint motion, navicular drop, and
foot posture index (FPI) were assessed after the completion
of the Par-Q questionnaire. Their survey information was ver-
bigally reviewed for accuracy and completeness. Height (m) and
body mass (kg) were recorded using a portable stadiometer
and electronic weighing scales, respectively (Seca, UK). A
certified athletic therapist (AB) and a chartered physiother-
apist with experience in musculoskeletal therapy (SD) completed
all testing components. Both testers practiced all aspects of
the protocol before testing under the instruction and supervi-
sion of a senior researcher and clinician. Because of the pres-
ence of multiple and bilateral injuries and potential recall
bias in remembering the side of injury, the average value of
the sum of both sides was used for each measure.

Isometric muscle strength. Isometric hip abduction, hip
extension, knee flexion, knee extension, and ankle plantarflexion
strength were measured using a dynamometer (J-Tech Com-
mander Echo Wireless Muscle Testing Starter Kit; J-Tech Med-
ical Industries, Midvale, UT) (Table 1) (17,18). Knee flexion
and extension and plantarflexion strength were tested using a
stabilization belt (17). Participants were directed to use

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maximum effort, while gently holding onto the side of the plinth for stabilization (18). Three repetitions were completed with 15-s rest intervals. The command “Go ahead-push-push-push-push-push and relax” was given for each contraction (18). The maximum value of three repetitions was documented and analyzed for each muscle group and was multiplied by the length of the resistance moment arm (m) and normalized to body mass (kg) (19).

**Navicular drop.** The navicular drop test was conducted as previously described (14). The medial and lateral aspects of the talus were palpated while sitting, and the foot was placed in a subtalar neutral position. The navicular tuberosity was palpated and marked, and the distance from the mark on the navicular to the floor was measured. A second measurement was recorded in the upright standing position. The average of three measurements of the difference between the sitting

| Movement Tested | Stabilization Belt | Patient Position | Dynamometer Position Protocol | Image of Testing |
|-----------------|--------------------|------------------|-------------------------------|-----------------|
| Hip abduction   | N/A                | Supine, knees in extension, hips in neutral | Positioned 5 cm proximal to the lateral malleolus (17). | ![Image](image1.png) |
| Hip extension   | N/A                | Prone, knee extended, hips in neutral. | Positioned on the posterior calf complex, in line with a mark that is 5 cm proximal to the medial malleolus (17). | ![Image](image2.png) |
| Plantarflexion  | Around the plinth and the sole of the subject’s shoe. | Prone, knees bent to 90° of flexion and foot in plantar grade. | Positioned between the belt and the metatarsal heads of the sole of the foot. | ![Image](image3.png) |
| Knee extension  | A suction plug was used to fix the stabilization belt to a concrete wall structure, allowing the tester to fasten the stabilization belt around the anterior aspect of the shank, proximal to the ankle joint (18). | Seated position with hips and knees flexed to 90°. | Positioned between the anterior shank and the belt, and participants were instructed to kick out against it. | ![Image](image4.png) |
| Knee flexion    | A suction plug was used to fix the stabilization belt to a concrete wall structure, allowing the tester to fasten the stabilization belt around the anterior aspect of the shank, proximal to the ankle joint. | Seated position, again with hips and knees flexed to 90°. Note: For the purpose of clear visibility, the other leg was staggered behind the testing leg. This was done in practice with both feet in parallel. | Positioned between the posterior shank and the belt, posterior aspect of the shank, proximal to the ankle joint (18). | ![Image](image5.png) |

N/A, not applicable.
and the standing heights was calculated for both feet. In addition, participants were categorized into two groups using the summed average navicular drop of >10 mm and <10 mm, as measurements exceeding 10 mm have previously been found to be related to injury (20).

FPI. The FPI was assessed with participants standing in a relaxed barefoot stance. Participants were instructed to remain as still as possible and were scored in accordance to the FPI-6 scale (21) and subsequently divided into foot type categories: as still as possible and were scored in accordance to the FPI-6 +5), pronated (+6 to +9), and highly pronated (+10 to +12) (22).

Joint motion. Ankle dorsiflexion, hip extension, hip internal rotation, and external rotation joint motion were assessed using a smartphone application (Plaincode clinometer,” V2.4 on a Samsung S8+, https://play.google.com/store/apps) (Supplemental Digital Content 1, http://links.lww.com/MSS/C284).

A knee-to-wall test was used to determine ankle dorsiflexion motion (23). Reduced ankle dorsiflexion motion has previously been suggested to be associated with compensatory pronation during running to achieve forefoot contact (8). This may consequently increase forces on surrounding structures. To perform this test, unshod participants faced a wall in a split stance. With one knee contacting the wall and the ipsilateral heel on the ground, participants gradually moved their foot as far away from the wall as possible, with their anterior knee maintaining contact with the wall. Participants were instructed to direct their knee anteriorly over the second toe. No additional effort was made for them to maintain a subtalar neutral position throughout the test. A smartphone was placed at the tibial tuberosity to measure the tibia angle relative to the ground. This was repeated three times and the average was recorded.

Hip motion has been suggested to be potentially related to injuries for two main reasons: (i) reduced motion may be reflective of shortened and therefore functionally limited hip muscles, and (ii) increased motion may signal potentially increased demands on musculature to control for excessive hip motion (24). Hip extension motion was assessed using the modified Thomas test (25). A resting measure of thigh position was recorded by placing a smartphone along the midline of the femur, 5 cm proximal to the superior surface of the patella, while the participant sat with their thighs supported on a firm plinth. The participant was then instructed to move to the edge of the plinth before being guided into a supine position by the tester. To control for lumbo pelvic motion, a biofeedback pressure cuff stabilizer was placed proximal to the posterior superior iliac spines of the lower back. The smartphone was again placed in the previous measurement position, and a reading was taken. The resting femur measure was subtracted from this reading to determine extension.

Hip internal and external rotation motions were measured with participants sitting with arms folded on the edge of a plinth (26). A smartphone was held against the fibula, 5 cm proximal over to the lateral malleolus, and a resting value was obtained. The hip was then passively maximally rotated on the frontal plane, with care taken to minimize compensatory movements. The smartphone was repositioned, and a reading was taken. The resting value was subtracted from this reading, and a resultant internal rotation measure was documented. This was repeated three times on each leg and averaged. The same procedure was repeated in the opposite direction to assess external rotation.

Good to excellent intraclass correlation coefficient values were found for interrater reliability (Supplemental Digital Content 2, Table A, http://links.lww.com/MSS/C285) and intrarater reliability (Supplemental Digital Content 2, Table B, http://links.lww.com/MSS/C285) of each of the measures.

Asymmetry. Asymmetry was calculated for each measure using symmetry angle (10), using the following equation:

\[
symmetry\ angle = \left[\left(\frac{45° - \arctan(X_{\text{dominant}}/X_{\text{nondominant}})}{90°}\right)\times 100\%ight]
\]

with a symmetry angle of 0% representing perfect symmetry.

RRI defined. Injury history was collected via an online questionnaire, which was completed before testing and reviewed (by SD or AB) with each participant for accuracy, at the time of testing. An RRI was defined as “any (training or competition) musculoskeletal pain in the lower limbs that causes a restriction/stoppage of running (distance, speed, duration, or training) for at least 7 d or 3 consecutive scheduled training sessions, or that requires the runner to consult a physician or other health professional” (27). Recently injured participants, who had been uninjured for 3 months to 1 yr before enrolment in the study, detailed the location of previous injuries and whether they had completed a rehabilitation program.

Statistical analysis. All data were analyzed with SPSS (version 23; IBM Corp., Armonk, NY). Participants were divided into three groups: recently injured (history of injury between 3 months and 1 yr, n = 116), acquired reinjury resistance (history of injury >2 yr, n = 61), and never-injured runners (n = 46). Differences in demographics between injury groups were assessed using one-way ANOVA. A two-way ANOVA (3 × 2) (group × sex) was used to evaluate differences in average bilateral and symmetry angle values for strength, navicular drop, FPI, and joint motion. Post hoc testing for significant interactions was performed using Gabriel’s test to accommodate for the uneven group sample size distribution. To further investigate any interaction effects, a simple slopes analysis was conducted. Data violating the assumption of homogeneity of variance were analyzed using separate Kruskal–Wallis tests to evaluate differences between injury group and sex. Effect sizes were reported using partial eta square (\(\eta^2\)) with 0.01, 0.06, and 0.14 representing small, medium, and large effect sizes (28). A chi-square test of independence was used to examine the relationship between FPI categories and the different injury groups. A separate chi-square test of independence was used to examine the relationship between the navicular drop <10 mm and the different levels of injury. Because of equipment malfunction, the sample size for each variable sometimes varied slightly and is detailed below.
RESULTS

Demographics. Two hundred and seventy-four (171 males, 103 females) recreational runners participated in this study. Of these, 116 (77 males, 39 females, 42%) had been injured 3 months to 12 months prior, 61 (38 males, 23 females, 22%) had been injured over 2 yr ago, and 46 (29 males, 17 female, 17%) had never been injured. Fifty-one participants (38 males, 23 females, 19%) were injured in the 1–2 yr before participating in the study and were excluded from analysis. This was done to ensure a clear demarcation between those who were theorized to have “acquired reinjury resistance” (injured >2 yr ago) and those that were recently injured (injured 3 months–1 yr previously). Of the runners in the recently injured group, 87% had participated in a rehabilitation program. A breakdown of the proportion of injuries for each injury location is detailed in Table 2.

No significant differences were found for any of the demographic variables of height, weight, and age between the three groups (P > 0.05, Table 3).

Normalized strength values. No interaction effect was found between injury status and sex for the strength values. A simple main effect between injury groups existed for hip abduction strength (P = 0.019, \( \eta^2 = 0.038 \), small effect size) and plantarflexion strength (P = 0.002, \( \eta^2 = 0.057 \), small effect size) (Table 4). Post hoc analyses revealed that recently injured (P = 0.001) and acquired reinjury resistance runners (P = 0.010) had significantly greater plantarflexion strength than never-injured runners. Recently injured runners had significantly greater hip abduction strength compared with never-injured runners (P = 0.001). A trend toward significance existed for greater strength among recently injured compared with those with acquired reinjury resistance, although this did not reach significance (P = 0.067). A significant main effect was found for sex for all strength values with significantly greater values among males when compared with females (P < 0.05; Table 5), except plantarflexion strength, which only approached statistical significance (P = 0.078).

Joint motion. No interaction effect was found between injury status and sex for the joint motion values. No significant main effect was found for injury status. Males displayed significantly

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**Table 2. The location of injuries among the recently injured group.**

| Injury Location      | No. Injuries at This Location | Percentage of Injuries at This Location (%) |
|----------------------|------------------------------|--------------------------------------------|
| Calf                 | 30                           | 20.4                                       |
| Knee                 | 19                           | 12.9                                       |
| Posterior thigh      | 18                           | 12.2                                       |
| Shin                 | 12                           | 8.2                                        |
| Foot                 | 11                           | 7.5                                        |
| Lateral thigh        | 10                           | 6.8                                        |
| Ankle                | 7                            | 4.8                                        |
| Lower back           | 9                            | 6.1                                        |
| Hip                  | 9                            | 6.1                                        |
| Buttock              | 7                            | 4.8                                        |
| Medial thigh         | 5                            | 3.4                                        |
| Heel                 | 5                            | 3.4                                        |
| Anterior thigh       | 2                            | 1.4                                        |
| Toes                 | 2                            | 1.4                                        |
| Sacroiliac joint     | 1                            | 0.7                                        |

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**Table 3. Table of subject demographics.**

| Group               | Total Males, Females | Recently Injured Males, Females | Acquired Reinjury Resistance Males, Females | Never Injured Males, Females |
|---------------------|----------------------|--------------------------------|-------------------------------------------|-------------------------------|
| N                   | 223                  | 116                            | 61                                         | 46                            |
| Age (yr)            | Mean ± SD            | 43.79 ± 9.26                   | 42.59 ± 9.36                               | 44.85 ± 8.96                  |
| Weight (kg)         | Mean ± SD            | 73.50 ± 11.62                  | 72.39 ± 12.86                              | 74.98 ± 10.11                 |
| Height (m)          | Mean ± SD            | 1.75 ± 0.10                    | 1.72 ± 0.094                               | 1.73 ± 0.09                  |

CLINICAL FACTORS OF INJURY-RESISTANT RUNNERS

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### TABLE 4. Descriptive statistics for each clinical measure.

| Clinical Test                  | Recently Injured | Acquired Reinjury Resistance | Never Injured |
|-------------------------------|------------------|-------------------------------|---------------|
|                               | Total N          | Males                        | Females       | Males                        | Females       | Males                        | Females       |
|                               | Males, Females   | (Mean ± SD)                  | (Mean ± SD)   | Males, Females                | (Mean ± SD)   | Males, Females                | (Mean ± SD)   |
|                               |                  |                              |               |                              |               |                              |               |
| Hip abduction strength (N·m·kg\(^{-1}\)) | 211              | 73, 34                       | 1.75 ± 0.33   | 1.84 ± 0.30                  | 1.59 ± 0.30   | 37, 22                       | 1.64 ± 0.28   |
|                               |                  |                              |               |                              |               | Males                        | Females       |
|                               |                  |                              |               |                              |               | 1.70 ± 0.27                  | 1.54 ± 0.27   |
| Hip extension strength (N·m·kg\(^{-1}\)) | 211              | 73, 34                       | 1.98 ± 0.50   | 2.07 ± 0.50                  | 1.80 ± 0.46   | 37, 22                       | 1.90 ± 0.41   |
|                               |                  |                              |               |                              |               | Males                        | Females       |
|                               |                  |                              |               |                              |               | 1.95 ± 0.42                  | 1.82 ± 0.38   |
| Plantarflexion strength (N·m·kg\(^{-1}\)) | 211              | 73, 34                       | 0.61 ± 0.23   | 0.64 ± 0.22                  | 0.57 ± 0.23   | 37, 22                       | 0.60 ± 0.20   |
|                               |                  |                              |               |                              |               | Males                        | Females       |
|                               |                  |                              |               |                              |               | 0.61 ± 0.19                  | 0.59 ± 0.23   |
| Knee flexion strength (N·m·kg\(^{-1}\)) | 209              | 72, 34                       | 1.40 ± 0.33   | 1.50 ± 0.32                  | 1.19 ± 0.26   | 37, 22                       | 1.37 ± 0.31   |
|                               |                  |                              |               |                              |               | Males                        | Females       |
|                               |                  |                              |               |                              |               | 1.47 ± 0.32                  | 1.23 ± 0.24   |
| Knee extension strength (N·m·kg\(^{-1}\)) | 210              | 73, 34                       | 1.37 ± 0.39   | 1.49 ± 0.35                  | 1.10 ± 0.34   | 37, 22                       | 1.35 ± 0.43   |
|                               |                  |                              |               |                              |               | Males                        | Females       |
|                               |                  |                              |               |                              |               | 1.47 ± 0.45                  | 1.15 ± 0.30   |
| Navicular drop (mm)            | 206              | 68, 37                       | 8.4 ± 2.8     | 9.7 ± 2.7                   | 7.8 ± 2.8     | 35, 20                       | 8.6 ± 3.3     |
|                               |                  |                              |               |                              |               | Males                        | Females       |
|                               |                  |                              |               |                              |               | 9.6 ± 3.4                    | 6.7 ± 1.9     |
| FPI                           | 212              | 70, 37                       | 7 (4.8)       | 6 (4.8)                     | 7 (4.8)       | 36, 23                       | 5 (3.7)       |
|                               |                  |                              |               |                              |               | Males                        | Females       |
|                               |                  |                              |               |                              |               | 6 (4.8)                      | 4 (1.6)       |
| Hip IR motion (°)              | 210              | 70, 38                       | 39.1 ± 6.0    | 38.1 ± 6.3                  | 41.0 ± 5.2    | 36, 20                       | 40.5 ± 5.8    |
|                               |                  |                              |               |                              |               | Males                        | Females       |
|                               |                  |                              |               |                              |               | 40.5 ± 5.6                   | 40.7 ± 6.2    |
| Hip ER motion (°)              | 210              | 70, 38                       | 36.9 ± 6.2    | 35.5 ± 5.7                  | 39.4 ± 6.4    | 36, 20                       | 36.2 ± 6.18   |
|                               |                  |                              |               |                              |               | Males                        | Females       |
|                               |                  |                              |               |                              |               | 36.2 ± 6.5                   | 36.3 ± 5.7    |
| Hip extension motion (°)       | 210              | 70, 38                       | 121 ± 7.7     | 117 ± 8.1                   | 128 ± 7.0     | 36, 20                       | 126 ± 7.7     |
|                               |                  |                              |               |                              |               | Males                        | Females       |
|                               |                  |                              |               |                              |               | 117 ± 7.9                    | 142 ± 4.5     |
| Ankle DF motion (°)            | 210              | 70, 38                       | 40.4 ± 3.4    | 40.4 ± 3.3                  | 40.3 ± 3.6    | 36, 20                       | 40.0 ± 3.9    |
|                               |                  |                              |               |                              |               | Males                        | Females       |
|                               |                  |                              |               |                              |               | 41.0 ± 4.7                   | 38.2 ± 4.9    |

*Median (first quartile, third quartile) was reported. N, number of participants; IR, internal rotation; ER, external rotation; DF, dorsiflexion.*

**DISCUSSION**

This study investigated the effects of injury status (recently injured, acquired reinjury resistance, never injured) and sex on lower limb strength, joint motion, and functional foot alignment, as well as the between-leg asymmetry of these clinical measures. Our findings largely did not support our hypothesis that injury-resistant and never-injured runners would have potentially distinctive clinical features, and differences between injury groupings were mostly nonsignificant. However, this study found significant associations between injury status and sex for the acquired reinjury resistance group placed them in the "neutral" (1 to 5) category. The median score for the acquired reinjury resistance group was significantly lower values of FPI (η² = 0.047, moderate effect size). Females with acquired reinjury resistance had significantly lower FPI compared with males (P = 0.009, η² = 0.021, small effect size). There was no significant association between injury status and sex for the recently injured group (Tables 4 and 5). A chi-square test of independence showed that there was no significant association between FPI and sex or main effects for injury status were found for symmetry angle of any variable. Females displayed greater lower limb internal rotation (P = 0.004, η² = 0.021, small effect size) and significantly greater ankle dorsiflexion motion (P = 0.038, η² = 0.02, small effect size) compared with females (P = 0.019, η² = 0.027, small effect size). Males with acquired reinjury resistance had significantly greater navicular drop compared with recently injured males (+7 [+4, +8]). The median score of recently injured males was significantly greater than that of females (+1 to +5). The median score of recently injured females was significantly lower than that of males (+1 to +5). A significant main effect was found for sex, with males exhibiting significantly greater navicular drop compared with females (η² = 0.003, small effect size). Females with acquired reinjury resistance had significantly lower values of FPI (η² = 0.047, moderate effect size). Females with acquired reinjury resistance had significantly lower FPI compared with males (P = 0.009, η² = 0.021, small effect size). There was no significant association between FPI and sex or main effects for injury status were found for symmetry angle of any variable. Females displayed greater lower limb internal rotation (P = 0.004, η² = 0.021, small effect size) and significantly greater ankle dorsiflexion motion (P = 0.038, η² = 0.02, small effect size) compared with females (P = 0.019, η² = 0.027, small effect size). Males with acquired reinjury resistance had significantly greater navicular drop compared with recently injured males (+7 [+4, +8]). The median score of recently injured males was significantly greater than that of females (+1 to +5). A significant main effect was found for sex, with males exhibiting significantly greater navicular drop compared with females (η² = 0.003, small effect size). Females with acquired reinjury resistance had significantly lower values of FPI (η² = 0.047, moderate effect size). Females with acquired reinjury resistance had significantly lower FPI compared with males (P = 0.009, η² = 0.021, small effect size). There was no significant association between FPI and sex or main effects for injury status were found for symmetry angle of any variable. Females displayed greater lower limb internal rotation (P = 0.004, η² = 0.021, small effect size) and significantly greater ankle dorsiflexion motion (P = 0.038, η² = 0.02, small effect size) compared with females (P = 0.019, η² = 0.027, small effect size).
resistance or never-injured runners. It has been suggested that increased strength may be protective against injuries because of the impact absorption properties of muscle (4), but findings to date have been mixed (7,19). Our findings have been supported by previous prospective research that found no link between hip extension, knee flexion, and knee extension strength and RRI (29). However, lower knee flexion and extension strength have been found to specifically predict a higher incidence of anterior knee pain (19), potentially indicating that strength may be related to specific injuries, which was not examined in this study.

Counterintuitively, hip abduction and plantarflexion strength were significantly greater among recently injured runners when compared with those who had never sustained an RRI. Previous studies of isometric hip abduction strength have found lower (30), higher (31), and no difference (32) in strength values among injured compared with uninjured runners. Although hip abduction strength of never-injured runners has been studied previously (10), data were not analyzed statistically, thus limiting the potential for comparison. Plantarflexion strength was also greater in the acquired reinjury resistance group compared with the never-injured group. This may indicate that compensations as a result of previous injury may persist in excess of 2 yr after the initial injury.

Although hypermobility and hypomobility have both been proposed to be related to musculoskeletal injury, a definitive link has not been established for RRI (8,24,40). This is further confirmed in a recent systematic review, which concluded that there was limited and low-quality evidence suggesting range of motion as a risk factor for running injuries (41). Our research support this as acquired injury resistance runners and never-injured runners did not display distinctive differences in dorsiflexion, hip external rotation, and hip extension motion compared with recently injured runners. Notably, in relation to hip internal

| Clinical Measure | P, Injury Status | Effect Size, Injury Status | P, Sex | Effect Size, Sex | P, Injury Status–Sex | Effect Size, Injury Status–Sex |
|------------------|-----------------|---------------------------|--------|-----------------|----------------------|-----------------------------|
| Hip abduction strength | 0.019* | 0.038 | 0.000* | 0.069 | 0.143 | 0.019 |
| Hip extension strength | 0.285 | 0.012 | 0.008* | 0.034 | 0.660 | 0.004 |
| Plantarflexion strength | 0.002* | 0.057 | 0.078 | 0.015 | 0.794 | 0.003 |
| Knee flexion strength | 0.471 | 0.007 | 0.000* | 0.125 | 0.678 | 0.004 |
| Knee extension strength | 0.257 | 0.013 | 0.000* | 0.141 | 0.826 | 0.002 |
| Navicular drop | 0.836 | 0.002 | 0.000* | 0.089 | 0.126 | 0.002 |
| FPI | 0.179 | 0.017 | 0.065 | 0.016 | 0.03* | 0.036 |
| Hip extension motion | 0.839 | 0.002 | 0.484 | 0.021 | 0.472 | 0.007 |
| Hip IR motion | 0.270 | 0.013 | 0.038* | 0.024 | 0.477 | 0.008 |
| Hip ER motion | 0.076 | 0.025 | 0.096 | 0.014 | 0.102 | 0.022 |
| Ankle DF motion | 0.215 | 0.015 | 0.019* | 0.027 | 0.148 | 0.019 |
| Hip abduction strength SA | 0.467 | 0.007 | 0.805 | 0.000 | 0.085 | 0.024 |
| Hip extension strength SA | 0.422 | 0.008 | 0.198 | 0.008 | 0.527 | 0.006 |
| Plantarflexion strength SA | 0.422 | 0.008 | 0.629 | 0.001 | 0.492 | 0.007 |
| Knee flexion strength SA | 0.572 | 0.005 | 0.037* | 0.021 | 0.950 | 0.001 |
| Knee extension strength SA | 0.240 | 0.014 | 0.577 | 0.002 | 0.733 | 0.003 |
| Navicular drop SA | 0.861 | 0.001 | 0.632 | 0.001 | 0.338 | 0.011 |
| FPI SA | 0.343 | 0.004 | 0.311 | 0.011 | 0.043 | 0.001 |
| Hip IR motion SA | 0.497 | 0.007 | 0.578 | 0.002 | 0.206 | 0.015 |
| Ankle DF motion SA | 0.636 | 0.004 | 0.753 | 0.003 | 0.411 | 0.003 |

*Significant difference between groups. SA, symmetry angle; IR, internal rotation; ER, external rotation; DF, dorsiflexion.
rotation, this finding conflicts with previous results, which found significantly higher hip internal range of motion among injured participants compared with never-injured runners (10), although different test positioning may account for the differences in results and their study had a smaller sample size (n = 40).

It is hypothesized that large amounts of joint motion may potentially increase demands on stabilizing muscles (24). Adaptive shortening or lengthening of muscles may also place muscles at nonoptimal lengths, limiting their functional ability (40). This is a marked limitation of traditional clinic-based strength tests performed in a stationary position, which typically do not account for the interaction between joint motion and muscle action. This study found no association between general injuries and joint motion. Although this is a commonly used measure in clinical practice, joint motion alone may not be able to differentiate between injury-resistant and recently injured runners. The lack of association calls into question its use in the management of general RRI, although it may be appropriate for screening for specific injuries (42) or used in combination with more dynamic muscle strength testing.

Foot alignment has been associated with changes in lower limb kinematics and loading during running (43), although the association between functional foot alignment and RRI has been conflicting (6,44). Contrary to our hypothesis, our study found no significant differences in either navicular drop means, the proportion of runners with navicular drop >10 mm, or FPI categories, suggesting that functional foot alignment largely does not appear to be protective against general RRI. An interaction effect between injury status and sex was found for FPI. Further analysis revealed that females with acquired reinjury resistance had significantly lower values of FPI compared with recently injured runners. It is unclear why this is, but it would suggest that females injured >2 yr ago have a more neutral foot type compared with female runners recently returned to play after injury, who had feet classified as “pronated.” We had hypothesized that navicular drop >10 mm would be associated with injury; however, assessing by cutoff point did not yield significant differences between groups in our study. This contrasts with a previous prospective study, which found this to be a risk factor for exercise-related leg pain among high school runners (20). Discrepancies in results may be due to our inclusion of more experienced recreational runners, a difference in age, or a variation in definition of injury. Notably, our findings conflict with those of Zifchock et al. (10) who found significantly reduced arch height index deviation from normal among never-injured runners; however, our study used a larger sample size and different measurement of functional foot alignment.
No differences in asymmetry were found between different injury groupings. This is in line with previous research, which found that asymmetry was not significantly different between never-injured and previously injured runners for hip strength and motion (10) or for strength values between uninjured runners and those in the early stages of patellofemoral pain syndrome (31). Limited research has found that asymmetries after injury may persist after return to play (9), despite the recommendation that asymmetries are minimized at this time point. However, for our cohort, it appears that similar levels of asymmetry existed across all groups, indicating that some level of asymmetry is normal. A finding of particular interest is that greater asymmetry was not found among those injured in the past year. Another explanation could be that studies which show high levels of asymmetry are generally related to acute, traumatic injuries, such as ACL ruptures (9), which may require greater rest than typical RRI. Our findings indicate to clinicians that some level of motion, isometric strength, FPI, and navicular drop asymmetry are to be expected among runners, regardless of their injury history.

Owing to the differences in RRI risk profiles that have been noted to exist between males and females (15), both the interaction effect of injury status on sex and the main effect of sex were investigated in this study. No interaction effects were found between injury status and sex for the clinical tests, except FPI. Sex may not have been a frequent interactive factor in our study as the majority of previous research finding sex-specific differences between injured and uninjured runners subdivided injury by diagnosis or location (8,31), which was not within the scope of this study. We found that compared with females, males displayed significantly greater knee flexion strength asymmetry, dorsiflexion motion, muscle strength normalized to body mass (except plantarflexion strength, which only approached significance), and navicular drop values, in addition to lower hip internal rotation. Previous research supports these findings with regard to strength (45), navicular drop (46), and hip internal rotation (47). Little previous information is available investigating the between-sex differences in knee flexion strength asymmetry. However, force production asymmetry has been found to be greater in females during jumping movements (48). Males displayed significantly greater dorsiflexion motion than females, contrasting with previous findings for healthy runners (46), although it is unclear why this difference exists.

A relatively unique component of this study was the examination of never-injured runners. It was hypothesized that investigating this group may have been useful in determining if common, easily assessable measures could identify potential differences in their clinical factors that may be protective of injury. Of the 223 participants analyzed in this study, 116 (77 males, 39 females, 42%) had been recently injured (<1 yr prior), 61 (38 males, 23 females, 22%) had been injured over 2 yr ago and were deemed to have acquired reinjury resistance, and 46 (29 males, 17 female, 17%) had never been injured. The most common location of injury was the calf, followed by the knee (Table 2), which is largely similar to what has been reported in previous literature (49).

Limitations. Despite being chosen for their suitability for use in clinical practice and potential association with common RRI, the clinical factors examined may have limitations. This study measured isometric contraction in a fixed position. Running also requires concentric and eccentric muscle action (50). Therefore, the muscle strength values measured within our study may not represent the typical values or contraction types produced during running. Similarly, quasi-static measures of navicular drop and FPI may not accurately reflect the dynamic motion of the foot during running. However, as these measures were considered to be more accessible in clinical practice, they were selected for this study.

The retrospective design of this study limits the ability to definitively ascertain whether differences between groups (recently injured, acquired reinjury resistance, and never injured) are as a result of injury or causative in nature. Compensation and postinjury rehabilitation may mask our understanding of the factors associated with injury, and while this information was collected for the recently injured runners, this was not gathered in the acquired injury resistance group. In addition, the injury history relied on accurate reporting from participants, meaning that it may be subject to recall bias. In an effort to minimize recall bias and due to the presence of multiple injuries, data were analyzed by grouping injuries together and averaging values from both sides. This method is advantageous in assessing whether there are factors protective from general RRI and not specific to a particular injury. However, this limited our ability to compare side-to-side differences, to examine injury-specific differences in clinical measures, or to delineate between overuse and acute injuries. Future studies should prospectively track injuries to minimize the effect of recall bias, while allowing the collection of a detailed injury history at the time of injury.

Conclusion. This study found that, in general, isometric muscle strength, joint motion, functional foot alignment, and side-to-side asymmetry values of these measures were not significantly different between runners who were recently injured, had acquired reinjury resistance, or were never injured. These findings suggest that injury-resistant runners cannot be distinguished from previously injured runners using popular clinical tests, likely because of high engagement with rehabilitation. Although these clinical factors may be important in the assessment and rehabilitation of injured athletes, the results of this study indicate that they have limited value in identifying future injury resistance of runners.

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