INTERNATIONAL JOURNAL OF
-EXERCISE SCIENCE-

Original Research

The Relationship Between Lower-Body Flexibility and Running Performance in a Half Marathon Downhill Running Event

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Abstract

International Journal of Exercise Science 18(3): 1-12, 2025. https://doi.org/10.70252/PYPQ3045
Although previous studies examining treadmill or relatively flat overground running events have found relationships for running performance and flexibility, no study has examined these outcomes during downhill events, including between sexes. Therefore, the purpose of this study was to determine if a relationship exists between lower body flexibility and running performance in recreational adult male and female distance runners competing in a downhill half marathon race. Recreational (n=11 male, n=19 female) adult distance runners completed this study. On the day prior to the race, participants performed a standardized warm-up, followed by determining their sit-and-reach flexibility. The next day, individuals ran their race and their performance scores were recorded using the race organizers website. Pearson correlation coefficients (r) were determined between race time and flexibility. Sex differences were determined using independent t-tests, with significance set at p<0.05. A significant relationship was observed across all participants for race performance and flexibility (r=0.42, p=0.01), but was not when separating out male (r=0.53, p=0.10) and female (r=0.32, p=0.19). Sex differences were observed for performance times (male: 6692.0±920.1 vs female: 7613.3±1073.5 sec., p=0.021, d=0.84), but not flexibility (male: 28.1±8.4 vs female: 32.9±10.8 cm, p=0.19, d=0.47). Flexibility is an important component of running performance, but may have less predictive ability by sex in downhill running performance in recreational runners.

Keywords: Sex differences, stiffness

Introduction

Long-distance running is a popular recreational and competitive sport worldwide[1] and is associated with many health-related benefits.[2] The growth of distance running is also very evident. For example, global participation in long-distance events (5 km up to ultramarathons) has boomed from ~2 million in 2001 to 10 million plus in 2016 and beyond, which includes all levels of competitors (youth to older adults, as well as recreational and sub-elite/elite).[1,3] With the vast growth of distance running as a sport, there has been a paralleled growth in research to all aspects of running performance, including, but not limited to, physiological predictors and training strategies.[1,4] Importantly, there are many training parameters (e.g., periodized endurance running training and resistance plus plyometric training), as well as environmental, biomechanical, anthropological, and psychological characteristics that are important for running performance.[1,4] Yet, in terms of physiological outcomes the three main parameters related to running performance from the classical model consist of maximal oxygen uptake (VO2max), the percentage of VO2max that can be sustained at a given work rate/speed, and running economy.[5] Related to running economy and performance, there is also growing evidence that flexibility should also be considered an important component of running performance[6–12] and is the focus of this study.

Flexibility can be defined as the total achievable excursion within the limits of pain of a body part through its range of motion.[13] In terms of flexibility and running outcomes, the majority of results have reported that some measures of lower limb flexibility are inversely related to running economy[6–12], although not always.[14–16] Gleim and colleagues, examined over 11 trunk and lower limb flexibility tests in a sample of 100 men and women aged 20-62 years and found that walking/jogging economy on a treadmill was the highest across various speeds for individuals with the tightest/lowest flexibility combined across all tests, whereas walking/jogging economy was the lowest across the same speeds for individuals with the loosest/highest flexibility[7]. The improved running performance from the inverse relationship of lower limb flexibility and running economy[6,7,9,11] is largely attributable to stiffer lower limb musculotendinous structures which improve energy transfer efficiency within the stretch shortening cycle of each foot strike.[17] Further, of the studies that have shown relationships between lower limb flexibility and running performance outcomes, the majority have been done on motorized treadmills with relatively flat (0-1% incline) surfaces.[6,7,9,11] Downhill portions can be found in many outdoor trail or road running races, and can impact running performance.[18–21] Compared to level or uphill running, downhill running alters running biomechanics (e.g., certain ankle, hip, and knee kinematics and kinetics) as well as running physiology (e.g., limb muscle electromyography's, running economy, excessive eccentric muscle contractions leading to muscle damage) to impact performance.[18–22] There are also reported differences in overground versus motorized treadmill running.[23] Also, to our knowledge, only two studies[10,16] have examined flexibility during an overground running distance race (i.e., relatively flat marathons) and the same authors found equivocal results based on sex. Specifically, in male recreational marathon runners lower limb flexibility was not related to marathon performance whereas in female recreational marathon runners, lower limb flexibility was significantly related to marathon performance.[10,16] Moreover, two additional studies from another laboratory found flexibility differences by sex (more flexibility in females than males) that also impacted running performance[12,15], which the authors attributed to differences in musculotendinous stiffness between sexes.[12,15] Thus, there is a need to examine the potential flexibility and running performance relationships in other settings and across sexes, like overground downhill running races in both male and female runners, which is the focus of this study.

Therefore, the purpose of this study was to determine if a relationship exists between lower body flexibility and running performance in recreational male and female distance runners of both sexes competing in a downhill half marathon race. We hypothesized that there would be a positive linear relationship between race performance and hamstring flexibility in male, but not female, recreational distance runners following a half marathon downhill race. Findings from this study will help to elucidate the impact flexibility has on running performance in male and female recreational runners during a primarily downhill event.

Methods

Participants

Participants for this study were selected from a group of recreationally active adults competing in the 2023 Cedar City Half Marathon in Cedar City, UT, USA. Recruitment was completed on site the day prior to the event. The total sample size that completed the study was 30 participants (*n*=11 male, *n*=19 female; Table 1). Informed consent was voluntarily completed by all participants prior to participation. Participants all stated to be in good health, and free of injuries that might have impacted the measurements in this study. The sample did not include any sub-elite or post-collegiate athletes, to maintain the recreationally active skill level of the participants. Permission to perform this study was received from the Southern Utah University Institutional Review Board (IRB; #15-082023b). This research was conducted in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). This research was carried out fully in accordance to the ethical standards of the *International Journal of Exercise Science*.[24]

Power analyses were conducted *a priori* with G*POWER 3.1.9.4 (Universitat Kiel, Germany) software to determine sample size. For a correlational analysis with a statistical power of $1-\beta = 0.80$, $\alpha = 0.05$, and effect size of 0.68 can be achieved with 9 participants for a single group. The 0.68 effect size came from previous work[9] showing a significant correlation between sit-and-reach flexibility and running performance in male distance runners. Further, previous work examining flexibility and running performance found sex differences with as little as *n*=4 per sex and up to ~n=10-12 per sex.[11,12,15] The current investigation was primarily powered for the correlational analysis of flexibility and running performance (requiring *n*=9 per sex) which we obtained *n*=11 males and *n*=19 females (30 total), but also for sex difference analyses.

Protocol

Half Marathon Race Details.

The race that was selected, the Cedar City Half Marathon, took place in Cedar City, UT, USA on September 9, 2023. The half marathon race was 13.1 miles or ~21.1 km long. Environmental conditions on race day at starting time were 10°C with wind at 12.9 km/hr. Conditions at the finish line varied depending on the participants finishing time with average values (with range) as follows: temperature = 25°C (21°C - 29°C,) humidity= 45% (34%-55%), windspeed= 10km/hr (6km/hr – 13km/hr). The road race course featured a significant downhill profile beginning at 2,490m of elevation, and finishing at 1,746m, with an average grade of -3.6% with a maximum grade of 5.8% and minimum grade of -11.7% (Figure 1).

Registration Packet Pick-Up.

The day before the race, September 8, 2023, all potential participants came to collect their registration packet and were recruited to complete an informed consent, demographic questionnaire with questions about age, height, weight, training status and experience, and participants lower body flexibility (described below) was also determined. Written consent from the race director was granted to recruit participants. Each participant's unique bib number was determined to access their race performance the following day.

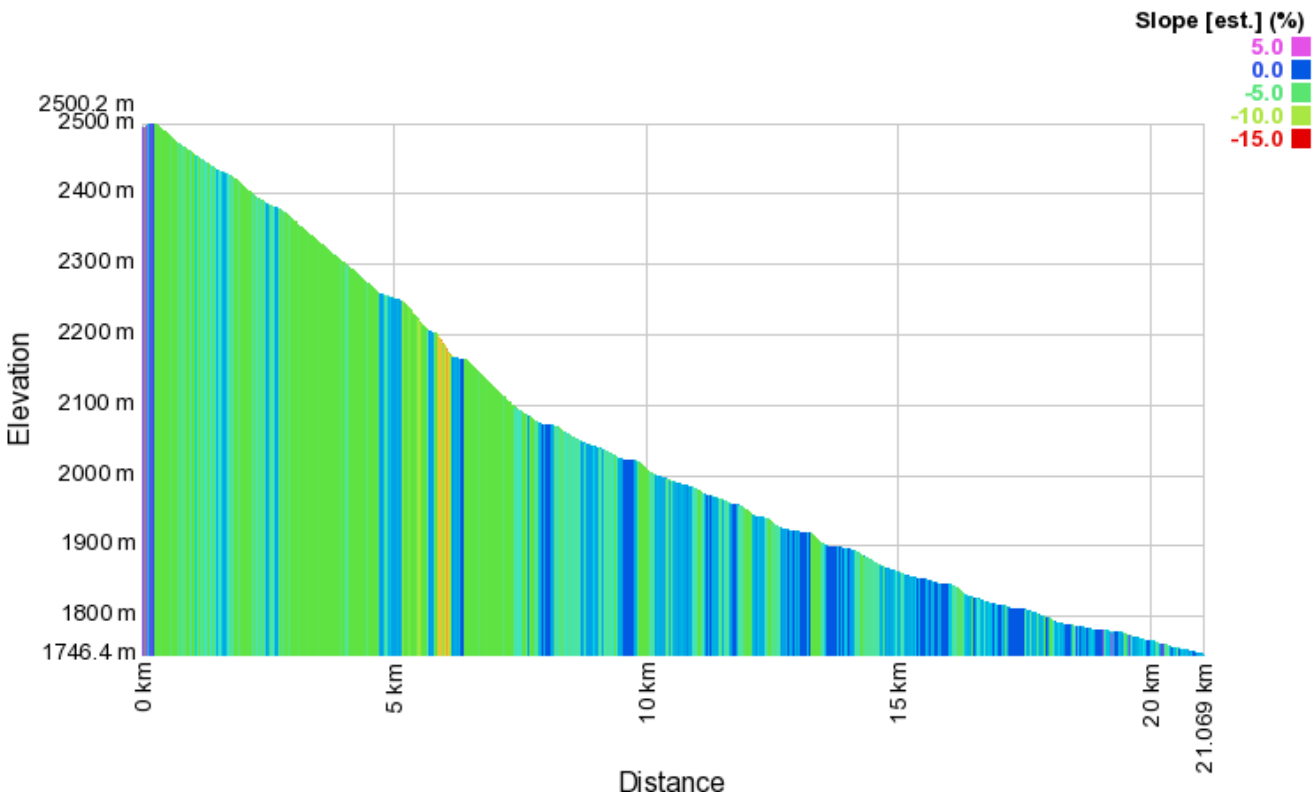

Figure 1. Elevation and slope profile of the Cedar City Half-Marathon.

Lower body flexibility.

Prior to any flexibility test, a standardized ~5 min. warm-up was completed that included light walking or running followed by dynamic stretches for 20-yards (~18.3m) each including high knees, walking lunges, butt kickers, hip internal/external rotation (open/close gates), and 2-4 progressively harder 20-yard sprints. Following the warm-up protocol, participants completed sit-and-reach flexibility testing following the National Strength and Conditioning Association (NSCA) protocol.[25] Sit-and-reach is recognized as having moderate mean criterion-related validity for determining hamstring flexibility (r=0.46-0.67), but not for lower back flexibility.[26] Further, sit-and-reach testing has also been shown to be highly reliable (ICC > 0.92) for measuring hamstring flexibility in male and female participants.[6,27]

Race Performance.

Race performance times were accessed through the race organizer's public website and were based on the chip time from participants unique bib's from start to finish. The unique chips normalized any differences in start time because of the crowded staging area/starting line of the race.

Statistical Analysis

A Pearson correlational analysis was used for comparisons between performance time and sit and reach scores and other variables (e.g., age), to determine a correlation coefficient (r value) for every comparison. Further, sex differences were determined using unpaired t-tests with Welch's correction to account for sample size differences by sex. We also calculated percent differences as well as effect size differences with Cohen's d. Effect size interpretations were as follows: 0-0.2 – trivial, 0.2-0.6 = small, 0.6-1.2 = moderate, 1.2-2.0 = large, >2.0 = very large.[28] Significance was set *a priori* at p<0.05 for all tests and data are reported as means ± SD. Prior to any statistical analyses the data were tested for normal distribution and equal variances to determine the appropriate statistical test. All statistical analyses and graphs were made using GraphPad Prism 10 (GraphPad, San Diego, CA, USA)

Results

Thirty recreational adult runners (*n*=11 male, *n*=19 female) completed this study (Table 1). Significant sex differences were observed for some variables but not others (Table 1).

Table 1. Participant characteristics.

Variable	Male Participants (*n* =11)	Female Participants (*n* = 19)	*p* Value	Sex Difference %	Sex Difference *d*
Age (yrs)	33.2±12.3	32.4±13.1	0.866	2.5 %	0.06
Height (cm)	178.5±6.2	164.6±8.0*	<0.001	7.8 %	1.40
Body Mass (kg)	81.6±12.7	61.8±10.1*	<0.001	24.3 %	1.36
BMI (kg/m²)	25.5±2.8	22.8±3.2*	0.022	10.6 %	0.83
Training Volume (km/wk)	27.5±15.3	22.8±9.9	0.383	17.1 %	0.38
Training Frequency (days/wk)	2.9±0.8	3.0±1.2	0.812	3.1 %	0.09
Training Experience (yrs)	7.6±12.6	7.0±6.5	0.872	8.8 %	0.07
Downhill Training (days/wk)	0.7±0.77	0.91±1.22	0.630	22.4 %	0.21
Sit-and-Reach Score (cm)	28.1±8.4	32.9±10.8	0.192	16.9 %	0.47
Race Time (sec)	6692.0±920.1	7613.3±1073.5*	0.021	13.8 %	0.84
Race Velocity (km/hr)	11.5±1.6	10.2±1.4*	0.024	12.0 %	0.89

Data are mean±SD; yrs = years, cm = centimeters, kg = kilograms, m = meters, km = kilometers, wk = week, sec = seconds, hr = hour. * = significant differences between sex.

Across all participants, there was a significant positive linear relationship between race times and hamstring flexibility (Figure 2A), but this relationship was non-significant when examining male (Figure 2B) or female (Figure 2C) participants independently. Race velocity (km/hr) also mirrored these findings with a significant (*p*=0.021) inverse linear relationship (*r*=-0.42) for all participants, but non-significant relationships were observed for male (*r*=-0.56, *p*=0.08) or female (*r*=-0.28, *p*=0.244) participants independently.

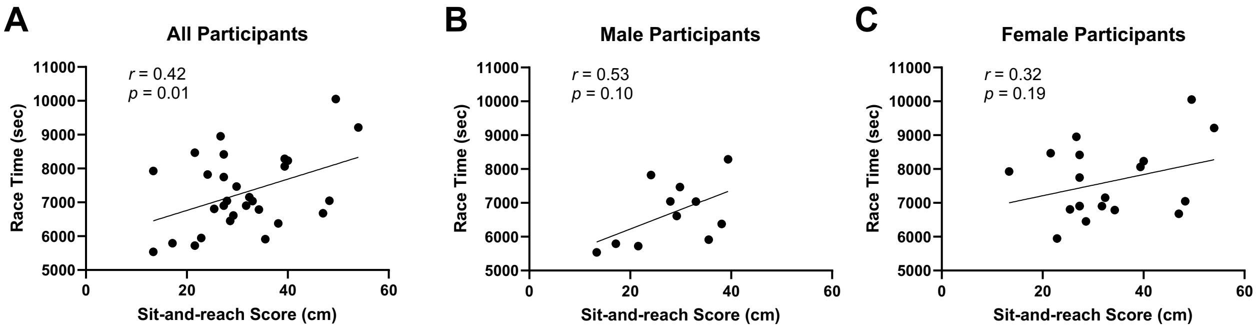

Figure 2. Relationship between race times and sit-and-reach score in all (A) recreational runners (n=19 female, n=11 male), or male only (B) and female only (C) runners following a half marathon downhill running event. A Pearson correlational analysis was used to determine the Pearson correlation coefficient (r), with significance set at $p < 0.05$.

Further, for all participants there were no significant relationships between hamstring flexibility or race performance times and any demographic or training outcomes (Table 2).

Table 2. Relationships between flexibility or race performance measures and certain demographic or training outcomes in recreational runners (*n*=19 female, *n*=11 male) competing in a half marathon downhill running event.

	Age (yrs)	Height (m)	Body Mass (kg)	BMI (kg/m²)	Training Volume (km/wk)	Training Frequency (days/wk)	Training Experience (yrs)	Downhill Training Frequency (days/wk)
Sit-and-reach Score (cm)								
Correl. (*r*)	-0.29	-0.13	-0.04	0.06	-0.14	-0.21	-0.26	-0.09
p Value	0.13	0.48	0.85	0.75	0.49	0.28	0.18	0.66
Race Time (sec)								
Correl. (*r*)	0.23	-0.21	-0.04	0.15	-0.21	-0.27	-0.22	-0.07
p Value	0.22	0.27	0.83	0.43	0.27	0.17	0.27	0.72

Correlation coefficient (r), yrs = years, m = meters, kg = kilograms, km = kilometers, wk = week, sec = seconds, cm = centimeters.

Discussion

The purpose of this study was to determine if a relationship exists between lower body flexibility and running performance in recreational male and female distance runners competing in a downhill half marathon race. Our hypothesis of their being a positive linear relationship between race performance and hamstring flexibility was partially supported, when looking at all participants there was a significant relationship which adds support to previous work.[6,7,9–12] However, the significant relationship was non-existent when examining male and female participants individually. The potential reasons for the lack of significant relationships between race performance and hamstring flexibility for males or female participants could be due to 1) the recreational athletes used in this study, 2) sex differences in flexibility and race performance, 3) the flexibility and running performance measurements used, and 4) the running type (i.e., level versus downhill and overground versus treadmill). The findings from this study add unique insights to the role hamstring flexibility have on race performance, with further understanding for how these variables differ across male and female participants following a downhill half-marathon event.

There is much previous support for lower-limb flexibility being strongly related to race performance measures while running[6,7,9,11,12], which again is largely attributable to improved stretch shortening cycle efficiency in each foot strike with stiffer lower limb musculotendinous structures. Our results across all participants adds to previous work. However, when examining these same relationships in male and female participants separately, the relationships were not significant for either sex, even though the correlation coefficient/relationship strength was higher in male (r=0.53) compared to female (r=0.32) and all participants (r=0.42). Nevertheless, one reason for the lack of relationships within each sex are potentially due to the sample being recreational athletes. Indeed, many of the previous studies to report significant relationships between flexibility and running performance were in competitive sub-elite/elite participants.[6,9,11,12] There are known differences in sub-elite/elite and recreational runners, such as training methods (e.g., technique, available training time, resources, injury prevention, motivation, to name a few), physiological (e.g., running performance parameters, genetics, anthropometrics) and psychological (e.g., running and competing motivations) outcome measures.[1,29–32] Further, within recreational runners themselves there are also known differences in training methods (e.g., periodization strategies, use of resistance training, etc.), running performance outcomes (e.g., aerobic/anaerobic capacity, running mechanics and economy, etc.), motivations (e.g., race for health, leisure, or performance), and also other important factors like sex and age.[1,2,30,32,33] In the only two studies to examine recreational runners, both found significant relationships between lower-limb flexibility and running performance when looking at combined male and female participants overall[7] or in male participants only.[34] However, these studies differed from the current investigation in terms of the flexibility and running performance measures (discussed below) which could explain the discrepancies. Thus, a main reason for the lack of significant relationships in male and female participants could be due to the heterogeneity of the recreational athletes used herein, as opposed to competitive sub elite/elite runners.[6,9,11,12]

One goal of the current investigation was to assess our outcomes by sex in recreational runners during a downhill running event. There was a moderate (d>0.80) 13.0% race velocity and 13.8% race performance time difference between sexes in the current investigation with males running faster than females, which is in line with previous work in long distance running events.[8,35] Moreover, the mechanisms for sex differences in these events have been largely attributable to intrinsic biological sex differences (e.g., metabolism, morphology, etc.) as well as sociocultural, psychological, and sport-specific factors.[8,35] Our study is the first to report sex differences in a primarily downhill half marathon running event. Although others have reported sex differences in lower-limb flexibility[7,11,12,15], we did not observe significant differences in our current sample, despite a small (d=0.47, 16.9%) difference. In the only other study to examine recreational [as opposed to competitive elite/sub-elite athletes who have also seen sex differences in flexibility[11,12,15]] male and female adults in the same study, Gleim and colleagues reported significantly less flexibility (tighter) in males compared to females for total body flexibility across 11 tests.[7] However, our current investigation only assessed hamstring flexibility with the sit-and-reach test and Gleim and colleagues did not, making direct comparisons difficult. Interestingly, when sex differences in flexibility have been reported[7,11,12,15], there are significant relationships between flexibility and race performance. Thus, the lack of significant sex differences in hamstring flexibility in the current investigation is another potential reason for the lack of relationships by sex for race performance and flexibility.

Another potential reason for the lack of relationships for both sexes between lower-limb flexibility and race performance are the sit-and-reach and race finishing time measures used herein. Importantly, studies that have used the sit-and-reach measure for hamstring flexibility have reported significant relationships between flexibility and running performance in non-recreational competitive men consistently[6,9,11,12], but competitive women's results have been equivocal[11,14,15], with the differences potentially due demographics, measurements used, or distances ran.[11,14,15] In the only two studies, to our knowledge, to use the sit-and-reach test as a measure of flexibility in recreational athletes during overground running the results were equivocal based on sex.[10,16] In particular, males did not have a relationship between sit-and-reach score with marathon running performance, but females did.[10,16] However, despite the current investigation finding no relationships by sex for these same variables, our study investigated these outcomes during a primarily downhill half-marathon event, with the other two studies being during a relatively flat marathon event[10,16] – more on this below. Moreover, other studies have used flexibility testing batteries, with and without sit-and-reach, and similarly found equivocal results for a flexibility and running performance relationship across sexes[6,7,14,34]. Also, our study examined race performance finishing times, whereas nearly all other studies examined flexibility related to running economy[6,7,9,11,14,34], except a few.[10,16] Running economy is a key aspect of running performance[5], but there are also a myriad of other factors (e.g., VO2max, performance VO2, anthropometrics, biomechanics, motivation, etc.) that also contribute to race performance times. Thus, potentially measuring running economy in the current study could have altered the results to be more in line with previous work. Regardless, using the measurements for lower limb flexibility and race performance does not support sex-specific relationships between these variables during a downhill distance event in recreational adults, and careful consideration is warranted for flexibility and running performance measures in future work.

The last potential factor for differences in our study's findings and others regarding flexibility and running performance is our study was with a downhill overground running race compared to level or treadmill assessments.[6,7,9,11,34] There are reported differences in overground versus motorized treadmill running[23], but these differences may not have been meaningful at the speeds individuals ran in our study, with likely differences not occurring until speeds are over 300 meters/min or 18 km/hr.[7,36] Yet, there are clear running mechanical and physiological differences between level and downhill running.[18,20,37] The again main reported mechanism for a positive relationship between flexibility and running performance during relatively level grades (~0-1%), being due to stiffer musculotendinous structures and efficiency of the stretch shortening cycle.[17] However, as the energy transfer for each foot strike is altered by downhill running[18,20] examining this relationship in a downhill event was needed. In particular, compared to level running, downhill running, especially as grades become more negative/steeper, lowers the center of mass resulting in higher foot strike impact loads and greater lower limb extensor muscle contractions with faster running speeds, these changes may enhance elastic energy storage and return through an exaggerated stretch-shortening cycle[18,20]. Even though there is a potential greater influence on running performance from enhanced stretch shortening cycle energy transfer with downhill running, our current study only supported the role of flexibility/musculotendinous structure stiffness during a downhill running half-marathon race when examining participants overall, but not when separating out into male and female runners. The lack of relationships between these variables, even during a downhill event, are likely due to what has been discussed above (e.g., recreational runners, no sex differences in flexibility, and the measurements used). There were also no reported sex differences in training outcomes within our current sample of recreational runners, including training volume, training frequency, training experience, and potentially most importantly downhill training frequency (Table 1). Furthermore, previous work has shown active females have substantially (up to 50-70+%) lower stiffness than males who are similarly active[38], which usually coincides also with males being less flexible than females.[7,11,12,15] Thus, the sex differences in running times/velocities may be due to sex differences in musculotendinous stiffness amongst other factors, even though we saw no flexibility differences. There also is potentially a greater need for eccentric strength (through resistance and plyometric training) than flexibility during downhill running to see enhanced performance[18,20,37], but that was not assessed presently. In another study that did assess lower-limb strength during level running in recreational male and females (with significant sex differences in flexibility), there were sex differences in strength, but there was no relationship between strength and flexibility for either sex.[7] Taken together, our current results along with others suggest that flexibility does not play a sex-specific role in predicting downhill distance running performance in recreational runners.

There are some limitations to our study, including gathering data from a single event, rather than a series of different races. Additionally, while using a wide range of people and experience levels adds great value to the real-world implications of our data for the average recreational runner, it also fails to control for individual level of motivation, previous race experience, previous training, etc. It could be valuable for future research to assess the personal motivations within the parameters of this study, as previous research has shown sex differences in motivational goals.[33] Additionally, teasing out the proper flexibility and running performance measurements needed to assess level versus downhill running in both sexes is also needed. Nevertheless, our study is the first to report sex-specific results for the role lower limb flexibility has on overground downhill running performance in recreational runners.

In conclusion, the purpose of this study was to determine if a relationship exists between lower-body flexibility and running performance following a downhill half-marathon race in recreational male and female runners. Our results support previous literature of a positive linear relationship between flexibility and race performance, but only when all participants were analyzed independent of sex. The results of our study do not support the use of flexibility as a predictor of downhill running performance in both sexes, but flexibility still remains an important component to consider for optimal race performance.[18,20,37] This study is useful for professionals around the world seeking to optimize real-world training conditions for recreational athletes and identify attributes of athletes of differing sexes who may have a biological predisposition for increased downhill running performance.

Acknowledgements

The authors declare that they do not have any competing interests associated with this work. The authors would like to extend our deepest gratitude to all participants and race organizers involved in helping to complete this study. L.P. and M.L. were responsible for conception and design of the experiments, acquisition, analysis, and interpretation of data, and drafting and critically revising the manuscript. All authors have approved the final version of the manuscript and agree to be accountable for all aspects of the work. All persons designated as authors qualify for authorship, and all those who qualify for authorship are listed. No funding was provided for this study and the authors have no conflicts of interest related to this study.

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