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Experience does not influence injury-related joint kinematics and kinetics in distance runners

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Abstract

Purpose: Increased running experience and more time spent running appears to be advantageous in reducing injury risk, although the reason behind this is unclear. It is plausible that more experience results in better running mechanics leading to less injuries. Running mechanics are often screened during clinical assessments and targeted for correction in gait retraining, particularly those thought to be global indicators of injury or those associated with elevated knee joint loading. Examining the biomechanics of runners who are less-injury prone can improve our understanding of the significance of faulty running mechanics in relation to injury. Our goal was to examine if running experience was correlated to differences in kinematics and kinetics associated with increased knee joint loading and running-related injury risk.

Methods: One hundred runners with varying experience ran on a pressure-sensing treadmill at a self-selected speed. Trunk and lower extremity kinematics, spatiotemporal measures, and ground reaction forces were collected. Multiple linear regression was used to assess the association between experience and three-dimensional hip kinematics, sagittal plane lower-extremity mechanics, and ground reaction forces while controlling for age and speed.

Results: Increased running experience was not significantly associated with running mechanics. Increased age was significantly associated with reduced peak knee flexion and increased contact time. Running speed influenced several spatiotemporal, kinematic, and kinetic variables.

Conclusion: Increased years of running experience does not appear to significantly influence running mechanics. However, age and running speed do influence biomechanical variables associated with injury in distance runners. Thus, there may be factors, other than running mechanics, that contribute to less risk in more experienced runners.

Keywords

Biomechanics; Running; Injury; Novice; Aging

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Conflict of interest
The authors have no conflict of interest to report.

1. Introduction

Lack of running experience has long been thought to be a risk factor for injury. Early epidemiological studies on running-related injury risk found that more years of running was protective against injury [1–3]. Recent investigations into running-related injury incidence found that when comparing time spent running, the rate of injury (injuries per 1000-h of running), in those with little to no running experience (novice runners) was 17.8 compared to 7.7 for recreational runners and 7.2 for ultra-marathon runners [4]. The running experience of recreational runners was unclear but included runners who either were running 10–25 km per week, had been consistently running in the last 12 months, or those who had taken part in marathon races in the past. Years of experience for ultra-marathoners was not described either, but one can surmise it is substantial. In relation to injury, experience is not an “all-or-none” factor. Individuals with less than 3 years of running experience were found to have more than twice the risk of injury (OR = 2.2) compared to more seasoned runners [5]. On an individual level, increased experience may also be protective against injury. van Mechelen and colleagues [5] found greater exposure times (i.e., more time spent running) led to lower relative injury risk. While many have cautioned there may be a “healthy runner effect” bias where injury-prone individuals discontinue running leaving only the healthy ones to become seasoned athletes [1,2,6], identifying the mechanism by which experienced runners stay healthy and can continue to run may further our understanding of injury etiology and improve prevention or rehabilitation programs.

Overuse injuries among runners are reported to be between 19% and 79% with the knee being the most predominant site of injury [7]. Novice runners have a higher reported incidence of knee and lower leg injuries compared to both short and long-distance runners of varying running experience [8,9]. A plausible cause for greater knee and lower leg injuries in novice runners could be that runners with little experience have poor running mechanics that result in higher loads on musculoskeletal tissue, particularly at the tibia and about the knee. The higher strain, despite lower weekly mileage and less years of accumulated loading, could explain why more experienced runners can run longer and usually faster [10] without incurring more injuries.

Specific kinematic and kinetic characteristics have been identified as *global* indicators of injury. For instance, vertical ground reaction force (VGRF) loading rates have systematically been found in runners with lower-leg and foot tendinopathies, tibial stress fractures, and unspecified running injuries [11]. Likewise, abnormal frontal and transverse plane movement patterns at the hip have been found in runners with tibial stress fractures, patellofemoral pain, and iliotibial band syndrome [12–16]. Additional kinematics that are not globally linked to injured runners but are associated with increased loads at the knee joint are foot strike angle, peak knee flexion, stride frequency [17] and peak trunk flexion [18].

While running-related injury is multifactorial, the aforementioned running kinematics and kinetics are often targeted in clinical gait retraining interventions as a means to reduce pain and restore function in runners with knee and lower leg injuries [19–23]. These biomechanical measures are also frequently assessed in a clinical setting to determine injury risk [24–26]. Years of experience may also contribute to reduced injury via improved musculoskeletal tissue tolerance to repetitive loading or refined training programs that allow for appropriate rest time. However, determining the influence of experience on running form will inform clinicians as to whether faulty mechanics in novice runners is a predominant factor for higher injury risk when starting a running program and may offer an immediate option (gait retraining) to reduce risk.

Little is known about the influence of experience on running biomechanics, particularly those biomechanical measures associated with elevated injury risk. To our knowledge, only one study has examined global indicators of injury for experienced versus novice runners [27]. That study, however, only examined female runners who had either been running for more than one year (experienced) or had not run consistently for at least 5 years but were physically active (novice). Likely, if a change in mechanics was to occur, it would happen gradually. Thus, the delineation of novice versus experienced at one year assumes that no significant changes occur after one year of running experience and that a significant change occurs within the first 12 months of running. A better understanding of mechanics, and subsequently the potential risk of injury, would come from studying running experience as a continuous variable rather than a finite threshold one achieves after running consistently for one year.

The objective of this study was to determine the extent to which running biomechanics related to injury, particularly of the knee, are associated with years of running experience.

2. Methods

2.1. Participants

One hundred distance runners (50 males, 8.4 ± 7.7 years running experience; range: 0–40 years) (Fig. 1) were recruited through word-of-mouth and flyers to local running clubs. Runners were healthy and free of musculoskeletal injury for the past 12 months prior to data collection. All participants were currently running at least 19 km per week with their shortest run being at least 5 km. On average, participants ran 45.9 ± 22.4 km per week, 10.9 ± 1.7 months of the year, and 4.5 ± 1.2 days per week. Runners were excluded if they had a lower extremity surgery within the last 6 months, wore custom or over-the-counter orthotics, or used a prosthetic device. Each participant provided written informed consent before involvement in the study. Data were collected following a protocol approved by the Institutional Review Board at the University of Michigan.

2.2. Experimental protocol

Participants were given adequate time to become familiar with the treadmill (Zebris Medical GmbH, Isny, Germany) prior to data collection. Participants ran at a self-selected running speed that was comfortable and representative of training pace. Data were collected subsequently for 5 min at this average running speed.

Lower-body and trunk kinematic data were measured with a wireless inertial measurement system (IMU) consisting of miniature IMU sensors that were securely taped bilaterally to the feet, shanks, and thighs; pelvis; and upper thorax (MyoMotion, Noraxon USA, Arizona, USA; maximal linear acceleration: ± 16*g*; maximal angular velocity: ± 2000°/s; 200 Hz). Per manufacturer instructions, shank and thigh sensors were placed laterally, halfway between the distal and proximal ends of the segment, and with the x-axis aligned to point superiorly along the long-axis of the bone. The pelvis IMU was placed posteriorly over the sacrum with the x-axis pointed towards the head. Likewise, the upper thoracic sensor was placed in the center of the mid-back and immediately distal to the T12 vertebra with the x-axis pointing superiorly. IMUs for the foot segments were placed on top of the feet over the midfoot region. The x-axis of each foot segment sensor pointed toward the toes. A subject-specific neutral-posture calibration was conducted prior to commencing running following manufacturer guidelines. Native algorithms integrated the calibration and sensor data to report three-dimensional segment orientations and accelerations and joint angles [28,29]. Underfoot pressure was collected at 120 Hz and used to calculate VGRF.

2.3. Data analysis

Biomechanical data from the final two minutes of the running trial were used for analyses. Custom Matlab (MathWorks Inc., Natick, MA, USA) programming was used to calculate running metrics. Foot contact and toe-off were identified when VGRF exceeded or fell below 5 N, respectively, and used to determine stride cycle parameters. VGRF active peak was determined as the maximum measured value during the step. Vertical GRF average loading rate was adapted from Milner et al. [30]. Joint kinematics were derived using variables obtained from available software (MyoMotion, Noraxon USA, Arizona, USA). Foot strike angle was calculated as the angle of the left foot relative to the horizontal in the sagittal plane at the instant of foot strike, with positive angles indicating toes above heel.

2.4. Statistical analysis

Descriptive statistics were calculated for each biomechanical variable. Multiple linear regression analyses were used to determine the influence of years of running experience on discrete kinematics and kinetics of interest while controlling for age and running speed. Statistical analyses were performed using Stata 15 (StataCorp, College Station, Texas). An $\alpha = 0.05$ was used to identify significant associations.

3. Results

Increased running experience was not significantly associated with biomechanical variables or spatiotemporal variables of interest (Table 1). Chronological age influenced running mechanics and self-selected speed (Fig. 2). Peak knee flexion ($\beta = -0.201$, $P = 0.04$, CI: −0.391 to −0.01) during contact phase decreased ($\beta = 0.0006$, $P = 0.04$, CI: 0.00004 to 0.0011) and contact time increased with increasing age in years (Fig. 3). VGRF loading rate, knee flexion at foot strike, peak knee flexion during contact phase, peak hip internal rotation during contact phase, stride rate, stride time, stride length, and contact time were significantly associated with running speed.

4. Discussion

The purpose of this study was to estimate differences in running biomechanics as a result of increased years of running experience. We focused our investigation on biomechanics that are associated with injury in runners. Since all runners, especially novice, have a high predisposition for knee injuries, discrete kinematics and kinetics associated with multiple running-related injuries (global indicators) and those associated with higher knee joint loading were assessed.

Increased years of running experience was not significantly associated with any biomechanical variables of interest. This supports other findings in the literature that have not found excessive lower extremity mechanics in novice runners. Schmitz et al. [27] found healthy runners with one year or more running experience to have larger hip adduction angles (16.7° ± 3.4°) than healthy novice runners (15.4° ± 4.5°). In this study, healthy runners were those who had not run for at least 5 years or had low self-reported physical activity levels. Others have found increased lower extremity hip and knee movement during running in an injured population. Noehren and colleagues [14] found that runners with iliotibial band syndrome had increased peak hip adduction angles compared to controls (14.1° ± 2.5° to 10.6° ± 5.1°). Greater hip adduction angles were also found in runners with patellofemoral pain (12.1° ± 2.8° to 8.1° ± 4.5°) [15]. The non-significant findings from both our study and Schmitz et al. [27] suggests that, at least initially, inexperience with running does not equate to poor lower extremity mechanics.

In this study, we examined discrete parameters of the VGRF curve that have been proposed to contribute to running-related injury. Higher VGRF loading rates have been found in runners with a history of injury [11]. Similarly, many researchers believe the reduced vertical impact peak evidenced in a forefoot strike pattern is protective against knee and lower-leg injury [31,32]. However, impact and active VGRF peaks were not found to be different in injured runners [11,33], and the influence of impact peak on injury remains controversial. Active VGRF peak has been considered a possible indicator of runner’s ability to counteract the forces of gravity at midstance such that higher values may indicate a greater muscular demand placed on the runner [34], which in turn could lead to greater risk of injury. However, contrary to our hypothesis, we did not find more years of running experience to be associated with positive effects on VGRF impact peaks ($p = 0.28$), active peaks ($p = 0.28$), or loading rates ($p = 0.88$). Likewise, sagittal plane landing mechanics like foot strike angle ($p = 0.75$) and knee flexion at initial contact ($p = 0.79$) were not significantly associated with experience. Peak knee flexion during stance, however, was significantly influenced by the age of the runner ($p = 0.04$). Older runners with the same years of running experience and running at the same velocity, had less knee flexion at initial contact. Increased age also significantly increased contact time ($p = 0.04$). It is still unclear whether longer or shorter contact times are better for running performance. Williams and Cavanagh [35] found that runners with higher VO_2 capacity has shorter contact times. However, elite male distance runners with a better running economy had longer contact times [36,37].

The impact of experience has the potential to be confounded by age given that as an individual continues to run he/she also continues to get older. This also may be why some have reported lower injury rates in older runners [38,1,39] because age and years of running experience are increasing coincidently. Thus, it was important to control for age when examining the influence of experience on running mechanics. Increased age only significantly influenced peak knee flexion during stance and contact time. This is in contrast to other studies that found increased age significantly alters running mechanics and loading parameters [40–42]. However, these studies did not control for velocity. Our findings suggest that running speed is a greater contributor to running mechanics and loading than age or years of running experience. A slower running speed was significantly associated with lower vertical GRF loading rates ($p = 0.001$), decreased knee flexion at foot strike ($p = 0.01$) and during stance ($p = 0.01$), decreased peak hip internal rotation ($p = 0.01$), reduced stride rate ($p = 0.004$), reduced stride time ($p = 0.003$), reduced stride length ($p = 0.001$), and reduced contact time ($p = 0.001$). As in this study, Conoboy [43] also found increased contact time with age even when running velocity was controlled. Taken together, these findings suggest that commonly-screened clinical global indicators are not influenced by years of experience but may be influenced by a runner's age or his/her current running speed.

Among the limitations of the study, we note its cross-sectional design. That limitation notwithstanding, the current study provides important information about the running mechanics associated with injury and years of experience. A second limitation was that force data were captured via a pressure-sensing treadmill; the 120 Hz sampling rate and back calculation of force data may have impacted detection of vertical impact peaks [44]. Consequently, kinetic variables should be interpreted more cautiously. Likewise, kinematic variables were determined from IMU-based motion capture rather than traditional optical motion capture. While IMU-based systems have been shown to be accurate, the anatomical angles reported differ slightly from the gold-standard optical systems [45,46]. Thirdly, it is important to note that older in our population was limited to 55 years or younger. This upper boundary of *older* runners was "younger" than previous studies suggesting that age-related changes in running mechanics may emerge earlier than 55 years or alter gradually with each passing year. Still unknown, however, is whether these changes are a natural result of the aging process or whether they represent an unconscious adaptation of movement patterns that have allowed some individuals to run for decades.

Findings from this study suggest that running experience does not significantly influence running mechanics, particularly those commonly screened for injury risk. It is plausible that factors other than deficits in discrete gait mechanics may be contributing to injury in less experienced runners. For instance, some runners may train in such a way that leads to beneficial musculoskeletal adaptation [47,1]. This would require runners to maintain an optimal amount of loading to positively improve their tolerance without causing excessive damage or strain. Investigation of the structure- and person-specific load tolerances in combination with running exposure [48] may give insight into the reduced risk some experienced runners display to injury and provide a guide for assessment and training in less experienced runners. Additionally, the value of experience to protect against injury may not be in improved running mechanics but in improved motor patterns and functional adaptability to the environment and/or biological stressors (i.e., training factors). Thus, experience may not be significant simply for years of participation but rather skill mastery and error correction. Investigating injuries in runners using a dynamical systems approach [49,50] and examining proficiency level rather than years of experience may give new insights into a runner's ability to respond appropriately to the environment [51] or indicate whether a runner is adequately "skilled" at running–considering it as an integrated "movement pattern".

5. Conclusion

Running mechanics are not significantly influenced by years of running experience. However, increased age appears to reduce the amount of peak knee flexion during contact phase and increased contact time. The extent to which these mechanics meaningfully alter performance or increase risk of injury in older runners is unknown. Speed appears to significantly influence many of the biomechanical variables commonly associated with heightened injury risk. Investigation into the influence of chosen running speed in novice runners and the associated alterations in running form may shed some light on why inexperienced runners incur more injuries than experienced ones.

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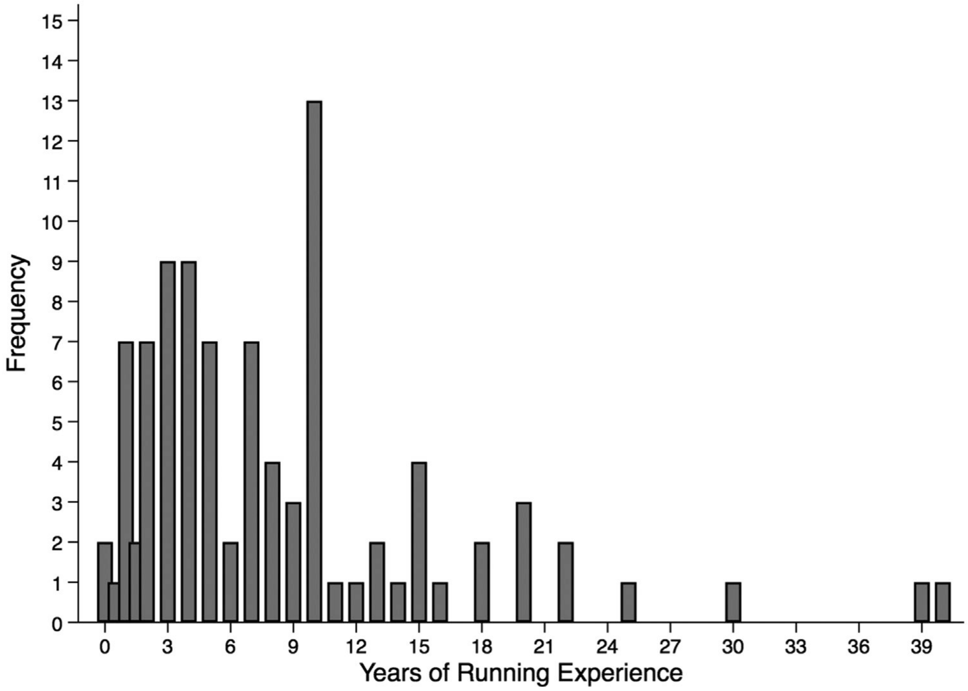

Fig. 1.

Distribution of years running experience for participants. Y-axis indicates frequency of participants with specific years of experience.

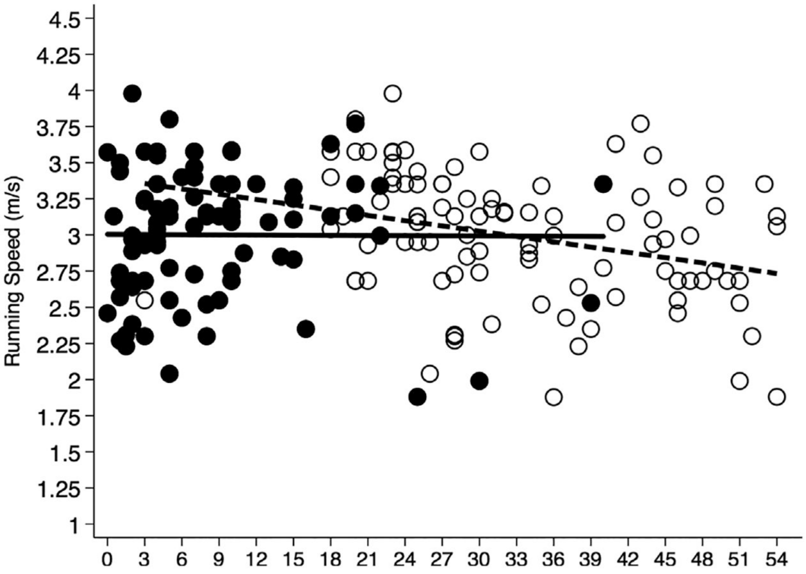

Fig. 2.

Scatterplot between running experience or chronological age and running speed. Black circles indicate years of running experience; white circles indicate age. Solid regression line has been fitted for experience while dashed line represents fitted values for age. Increased age was significantly associated with reduced running speed ($ß = 0.0006$, $p = 0.04$, $CI_{95} = 0.0004, 0.001$).

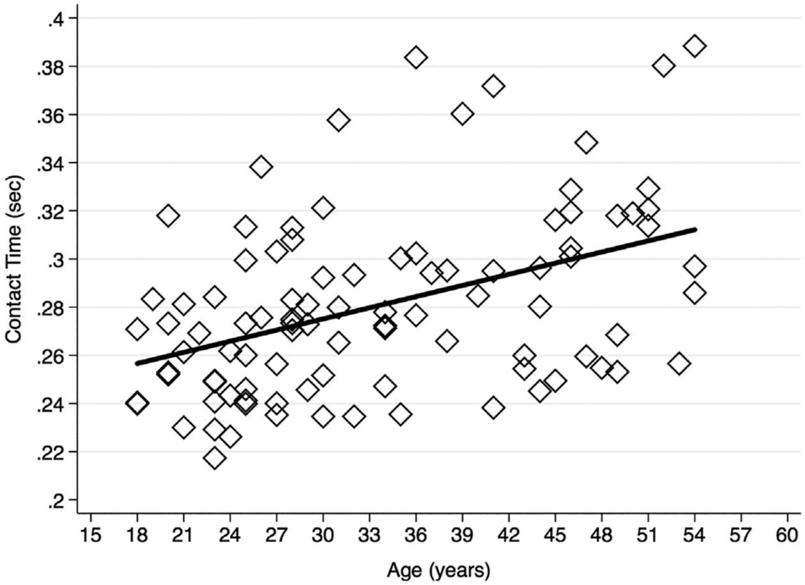

Fig. 3.

Scatterplot between contact time and chronological age. Solid regression line has been fitted for contact time values related to age. Increased age was significantly associated with increased contact time ($ß = -0.014$, $p = 0.002$, $CI_{95} = -0.023, -0.001$). Years of running experience was not significantly associated with running speed ($ß = 0.0081$, $p = 0.19$, $CI_{95} = -0.005, 0.021$).

Table 1

Linear regression parameters for discrete kinematics, kinetics, and spatiotemporal measure parameters. Coefficients, *p*-values, and 95% confidence intervals are listed for each predictor variable. Significant P-values are bold and italicized.

Parameter	Coefficient	P-value	95% Confidence Interval
Vertical impact peak (BW)			
Age	0.026	0.75	−0.137 0.189
Velocity	−3.05	0.11	−6.77 0.678
Experience	0.121	0.28	−0.100 0.342
Loading rate (BW/s)			
Age	−0.092	0.54	−0.390 0.206
Velocity	16.4	0.001	9.601 23.2
Experience	−0.031	0.88	−0.436 0.373
Active Peak (BW)			
Age	0.026	0.75	−0.137 0.1895
Velocity	−3.046	0.11	−6.77 0.678
Experience	0.121	0.28	−0.100 0.342
Foot strike angle (°)			
Age	0 0.361	0.15	−0.130 0.853
Velocity	−5.52	0.33	−16.7 5.691
Experience	0.108	0.75	−0.562 0.778
Knee flexion at foot strike (°)			
Age	−0.245	0.23	−0.648 0.158
Velocity	11.67	0.01	2.489 20.846
Experience	−0.225	0.42	−0.774 0.324
Peak knee flexion during contact (°)			
Age	−0.201	0.04	−0.391 −0.01
Velocity	6.024	0.01	1.573 10.475
Experience	−0.035	0.79	−0.293 0.224
Peak hip adduction during contact (°)			
Age	−0.034	0.62	−0.167 0.099
Velocity	2.417	0.12	−0.610 5.445
Experience	0.006	0.95	−0.175 0.187
Peak hip internal rotation during contact (°)			
Age	−0.079	0.31	−0.235 −0.076
Velocity	5.059	0.01	1.525 8.593
Experience	−0.104	0.33	−0.3158 0.107
Peak trunk flexion during contact (°)			
Age	−0.066	0.41	−0.225 0.093
Velocity	2.710	0.14	−0.914 6.335
Experience	−0.082	0.46	−0.298 0.135
Stride rate (strides/min)			

Parameter	Coefficient	P-value	95% Confidence Interval
Age	0.085	0.48	−0.152 0.322
Velocity	8.049	0.004	2.628 13.471
Experience	0.0305	0.85	−0.292 0.353
Stride time (s)			
Age	−0.0003	0.46	−0.0014 0.0006
Velocity	−0.035	0.003	−0.059 −0.012
Experience	−0.0004	0.85	−0.0015 0.0013
Stride length (m)			
Age	−0.00005	0.12	−0.00012 0.00001
Velocity	0.0107	0.001	0.0092 0.0122
Experience	−0.00004	0.93	−0.00009 0.00009
Contact time (s)			
Age	0.0005837	0.04	0.00004 0.0011
Velocity	−0.0566981	0.001	−0.0692 −0.0442
Experience	−0.0003	0.45	−0.001 0.00046
Flight time (s)			
Age	0.0015	0.33	−0.0016 0.0046
Velocity	−0.0120816	0.73	−0.082 0.058
Experience	−0.0023301	0.27	−0.0065 0.00185