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GAIT BIOMECHANICS AMONG FEMALE ENDURANCE RUNNERS: COMPARING DAYS WITH OR WITHOUT MENSTRUAL CYCLE-RELATED SYMPTOMS

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Gait Biomechanics Among Female Endurance Runners: Comparing Days With or Without Menstrual Cycle-Related Symptoms

Abstract

Objective: Determine differences in running biomechanics in female endurance runners between days when they did and did not report menstrual cycle-related symptoms.

Methods: Observational study. Subjects were provided RunScribe sensors to attach to their shoes to collect biomechanical data when running. Daily during the study period, subjects were sent a text message to complete a survey asking about their wellness, menstrual status, and training status. Descriptive measures (mean ± SD) were generated for whether runners reported being asymptomatic or symptomatic during runs and run workout details. Paired sample t-tests were executed to identify differences in impact Gs, braking Gs, pronation excursion, maximum pronation velocity, foot strike type, and gait speed between runs on days participants reported having menstrual-related symptoms (symptomatic) or not (asymptomatic). Participants needed to have recorded runs spanning the entire data collection window to be included for comparative analyses.

Results: Twenty-seven university club runners (age 20.5 ± 1.5) participated in the study. All runners ($n = 27$) experienced at least one menstrual cycle-related symptom during data collection. The average number of asymptomatic runs was 22.3 ± 17.1 and symptomatic runs was 9.1 ± 7.5. Daily mileage averaged 4.3 ± 1.9 miles and total mileage was 154.2 ± 115.4 miles. Fourteen runners had run data viable for pairwise sampling. There was no significant difference in biomechanical measures between symptomatic or asymptomatic days ($p > .05$).

Conclusion: This study prospectively monitored distance runners' activity while simultaneously recording symptoms related to the menstrual cycle. While runners reported fewer days running

when symptomatic, we did not identify a difference in objective biomechanical measures between asymptomatic or symptomatic runs. Perceived symptom burden was present in this sport population and may warrant further exploration of perceived expectations of the menstrual cycle to athletic performance.

INTRODUCTION

Running is a popular sport due to known positive health benefits.[1] Recently, sport science literature has been reviewed to identify if there was a difference in study participation by sex.[2] It was determined prominent sport science journals had a low volume of female study participants, even when studies were not addressing male-specific physiology.[2] When females are not represented in research, assumptions can manifest that females will respond and perform the same as their male counterpart. Yet, how an athlete moves[3] during activity is one of many sex differences that have been identified between male and female athletes.

Within running, there are known biomechanical differences between males and females.[3] Females can present with increased frontal plane hip adduction and knee adduction.[4] The majority of biomechanical running studies have been conducted in a controlled lab setting.[3] This may not accurately represent potential biomechanical changes, such as those related to musculoskeletal pain or other symptoms exclusive to females, observed during their routine outdoor runs. Wearable technology can allow the scientist to track biomechanical measures over time in a natural environment for the female runner.

The commercial availability of wearable technology has made it feasible to acquire a multitude of training variables with ease.[5] In sport science literature, training variables are often quantified as a work load that can be separated into internal and external components.[6] Common internal work load measures include heart rate and rating of perceived exertion, whereas external work load measures include metrics such as distance run, gait speed, and biomechanical measures quantifying accelerations, decelerations, and other movement parameters.

When considering new technology for data collection use, it is important that the device can measure what it is intended to measure. RunScribe (Scribe Labs, Moss Beach, CA) is a shoemounted wearable sensor that can collect spatiotemporal, kinetic, and kinematic data when an individual is running. It has been demonstrated to be valid in the measure of spatiotemporal[7] (i.e., cadence, stride length, contact time), kinematic[8] (i.e., pronation excursion, maximum pronation velocity), and kinetic[9] (i.e., impact G, braking G) outcomes during running. The RunScribe sensors are designed and marketed to measure select biomechanical variables during outdoor running. Because it is not feasible to directly compare simultaneous measures from the sensors to gold standard 3D motion analysis and force plate measures during continuous outdoor running, our research group has systematically developed a portfolio of validity evidence to justify use of the RunScribe sensor measures in applied settings. These include correlation of simultaneous measures during treadmill running with a gold standard 3D motion capture system[8,10], demonstrating expected changes in measures when running on different surfaces and different speeds[9], demonstrating changes in measures when running under different conditions such as ankle taping, bracing, and control conditions[11], demonstrating differences in measures between pathological and healthy runners including chronic ankle instability[12] and exercise-related lower leg pain[13,14], and the ability to change measures following targeted clinical interventions in runners with exercise-related lower leg pain[14]. Collectively, this evidence demonstrates a portfolio of validity for the RunScribe sensors to justify use in the measurement of gait biomechanics during outdoor running. Wearable sensors, such as the RunScribe, can allow clinicians to obtain objective data within the natural environment the athlete is running in.

Specific to female physiology is the menstrual cycle. On average a menstrual cycle can last from 21-35 days. Female athletes have reported a perceived negative impact to their performance from menstrual cycle symptoms.[15,16] The term ‘performance’ can be applied to when athletes are engaging in training or competition situations for their respective sport. When there is a negative perception tied to their symptoms, it is common for athletes to consider modifying or discontinuing their training plans when experiencing menstrual-related symptoms.[17] Studies focused on auditing hormonal contraceptive use among female athletes have reported 41%[18]-68%[19] of their respective study sample were taking a hormonal contraceptive. Reasons for taking a hormonal contraceptive could be to manage when an athlete is bleeding or to mitigate menstrual-cycle related symptoms[20]. While taking a hormonal contraceptive may be a common strategy among athletes to address these concerns, menstrual cycle-related symptoms are still being reported[21]. It is not known if there are differences in symptoms experienced between female athletes who are and are not taking a hormonal contraceptive.

Endurance runners are a unique sport population due to the high volume of training that is accrued relative to the number of races completed.[22] Perceived changes in performance due to menstrual-related symptoms have been reported regardless if the athlete is participating in a team or individual sport.[23] Biomechanical measures have not been measured in a natural environment in conjunction with recording menstrual cycle-related symptoms. Whether or not runners experience changes in their sport performance due to menstrual cycle-related symptoms is unclear.

When attempting to measure sport performance**,** an objective metric should be included (e.g., time to complete a 5k race, or impact G's when running on concrete). Qualitative literature supports that females perceive symptoms related to their menstrual cycle yield a negative sport performance.[15,23] When assessing an athlete's work load it is indicated to capture internal and external variables so there is a robust representation of the athlete's response to the training stimulus.[6] To the author's knowledge, no study has yet to prospectively track menstrual cycle-related symptoms in conjunction to collecting objective biomechanical measures in distance runners. The purpose of this study was to measure biomechanical outcomes during training over time in relation to reported menstrual cycle symptoms in a female endurance running population to better understand the impact of perceived menstrual cycle-related symptoms on running biomechanics. We expected to observe changes in the runner's biomechanical performance variables when the athlete reported menstrual cycle-related symptoms.

METHODS

Participants

Subjects were recruited through the University of XXX Club Running Listserv. An email was sent detailing the purpose of the study and inclusion criteria. To be considered for participation, subjects had to be aged 18-45, be of the female sex, have had at least one period, exercise vigorously at least 75/minutes a week[24], and compete in races of 1500m or greater distance. Interested prospective subjects who met inclusion criteria could reply via the recruitment email to the primary investigator to schedule their baseline visit. All prospective subjects who met for a baseline visit were included in the study. Two cohorts were recruited. The first was recruited January 2023 for data collection to run through April 2023. The second cohort was recruited from June to August of 2023 and subjects were in active data collection for 90 days total. Twenty-seven subjects were included between the two cohorts. While all 27 subjects were included for descriptive measures, only fourteen subjects had viable run data for comparison analyses. Some athletes discontinued reporting run data within one month of being enrolled (n = 7) or did not consistently record runs spanning three months (n = 6).

Procedures

During their baseline visit, subjects reviewed and signed a consent form, completed a baseline questionnaire, downloaded the RunScribe application to their phone, and went through a calibration process for the RunScribe sensors. Thereafter, they were instructed to wear the sensors whenever they went running regardless of surface type or workout plan. Every day during the data collection period a text message was sent with a link directing subjects to complete an online daily survey. Active data collection lasted 90 days per participant. The baseline and daily survey were both administered using Qualtrics (Seattle, WA). Subjects needed to consistently record runs spanning the three-month collection window to be considered for comparison analyses. This study was approved by the university institutional review board.

Daily Survey Instrument

The daily survey was delivered to subjects via text message every evening at 6:30pm local time. If the survey was not completed within 30 minutes, a reminder message was sent at 7:00pm. The text message contained a link that redirected the subject to a Qualtrics (Seattle, WA) web page with a mobile version of the survey to complete. Items in the survey included recording their RunScribe sensor number, questions about their training details for the day (e.g., subjects could select if they 'ran', 'cross-trained', or if it was a 'rest day/withheld from activity'), menstrual cycle symptoms experienced (derived from preexisting work[16]), and responses to wellness questions via the Short Recovery and Stress Scale. If one or more symptoms were selected on the daily survey, this was considered a 'symptomatic day'. When no menstrual cycle-related symptoms were selected, this was categorized as an 'asymptomatic day'.

RunScribe Sensors

The RunScribe sensors (Scribe Labs, Moss Beach, CA) house a tri-axial accelerometer and gyroscope with a sampling rate of 200 Hz.[10] We used these devices to collect kinetic and kinematic data (see table 1). It has yielded successful concurrent validity when compared to the gold standard, 3D motion capture system.[7,8] Upon completion of the baseline survey, subjects downloaded the RunScribe application onto their mobile phone to allow for tracking of their running data. Thereafter they would go through a sensor calibration procedure including a quiet stance task and a predetermined distance run. A quiet stance and predetermined run were completed to calibrate the sensors for subject use. The predetermined run was an out-and-back route from the testing site with total distance of 0.88 miles. Subjects were instructed to run at a self-selected comfortable run pace. During the baseline visit, subjects were provided a PDF document detailing how to position the sensors on their shoes and login information to access the RunScribe application via their phones. Upon successful fitting of the sensors to the subjects' running shoes, they were instructed to stand and be still during the quiet stance calibration. Thereafter, subject and investigator went outside to complete the calibration run. Subjects were shown a map of the run route prior to departure, and shown how to start a 'run' on the RunScribe app. Subjects did not have to run with their phones due to the sensor having data storing capabilities. Once the subject had returned from the run, the 'run' was stopped on the app and synced to the phone application via Bluetooth. The distance recorded on the app was manually updated if it did not match the predetermined distance. This was the only time the run distance was manually manipulated. Subjects were discouraged from changing any data collected on the phone application. Run data was transferred via a wireless network from the phone application to RunScribe's website for storage. Each sensor had an individual account that could be accessed by a master account through RunScribe's website.

Data Processing

The primary investigator accessed runs via the RunScribe website for each runner. Runs were reviewed by date and were considered for analysis if recorded distance equaled or exceeded one mile and there was data for both limbs. Data was exported as .csv files and converted to Excel files (Microsoft, Redmond, WA) for cleaning. Flight time was used to ensure data collected for each run did not include time when the runner was walking or standing. Any rows of data where flight time equaled zero (i.e., when the sensor recorded the subject not running) were removed for each file. Biomechanical variables of interest were exported in a new file version where average values for each foot were then consolidated to obtain a mean value for each metric by run. The new mean values for each variable were then averaged to yield a single score for each subject to include for statistical analysis.

Statistical Analyses

Descriptive measures (mean ± SD) for all study participants included the following: total symptomatic and asymptomatic days reported when running, cross-training, or resting/withheld; average daily run distance when symptomatic and asymptomatic; total mileage; running frequency; and running surface types. Paired-samples t-tests were conducted (SPSS version 29.0.2.0, Chicago, IL) to compare the biomechanical measures on symptomatic and asymptomatic days. Three groups of t-tests were completed on: 1) the total sample 2) only runners cycling naturally (NC), and 3) only runners taking a hormonal contraceptive (HC). Outcome variables of interest were gait speed, braking G's, impact G's, maximum pronation velocity, pronation excursion, and foot strike type. RunScribe's predetermined foot strike type was categorized as forefoot (value: 11-16), midfoot (value: 6-10), and rearfoot (value:1-5).[10] Data are reported as mean ± SD, mean difference, Cohen's *d* effect size, and p-value. Effect size was calculated using the following interpretation: ≥0.8 large; 0.5-0.79 moderate; 0.2-0.49 – small; ≤0.19 –trivial.[25] A priori statistical significance was set to p<.05.

RESULTS

Twenty-seven runners (age = 20.5 ± 1.5 years) were enrolled for study participation and the average age at which participants started running was 14 ± 2.1 years. Demographics are summarized in table 2 and self-reported menstrual cycle characteristics are summarized in table 3. The number of days run during the study period while asymptomatic was 22.3 ± 17.1 and symptomatic was 9.1 ± 7.5. The average daily mileage was 4.3 ± 1.9 miles for asymptomatic days and 4.2 ± 2.0 miles for symptomatic days. Average total mileage was 154.2 ± 115.4 miles (see figure 1). The most common running surface was concrete (n = 433, 50.9%), see table 5 for additional surface types.

There were no significant differences when comparing symptomatic runs to asymptomatic runs by the entire sample, those taking a hormonal contraceptive, or those who reported a natural cycle to biomechanical measures (p > .05, see tables 7, 8, and 9). Effect sizes across all comparisons were considered trivial or small (d ranging from -0.1 to 0.46).

DISCUSSION

The purpose of this study was to identify if running gait biomechanics differed on days when female runners did or did not report menstrual-related symptoms. We did not identify significant differences in any biomechanical measures collected on runs performed on symptomatic versus asymptomatic days. Importantly, average gait speed was nearly identical between runs that occurred on symptomatic and asymptomatic days thus indicating that systematic performance deficits were unlikely to be related to the presence of menstrual-related symptoms. More days were logged running when subjects reported being asymptomatic versus symptomatic. Daily mileage was also similar between asymptomatic and symptomatic days. To the author's knowledge this is the first study that prospectively tracked running biomechanical measures in conjunction to collecting menstrual cycle-related symptoms in an endurance running population.

Our study did not identify significant differences for running biomechanical outcomes on days runners reported being asymptomatic versus symptomatic (regardless of contraceptive use). Additionally, the effect size estimates between kinematic and kinetic measures indicated small differences in measures between symptomatic and asymptomatic days. Most literature that has previously explored the effects of the menstrual cycle in female athletes has attempted to identify differences in sport performance across the different menstrual cycle phases.[26] One study looked at changes in aerobic capacity via VO_2 peak, maximal heart rate, and blood lactate levels during a submaximal test on a treadmill or bicycle.[27] Testing was conducted at three different time points to represent different phases of the menstrual cycle, yet did not identify any significant changes in these outcome measures of internal work load.[27] Another study which only included NC females (n = 8) looked at kinetic variables during running across menstrual cycle phases at three separate visits in a lab setting.[28] They did not identify any differences in external work load measures, specifically impact G's and braking G's, across different menstrual cycle phases.[28] This is somewhat similar to our findings where we did not identify a significant difference in biomechanical variables measured during outdoor running on days when participants reported having or not having menstrual-related symptoms. Sprinting (repeat 20-meter sprint test) and jumping capacity (countermovement jump height) have also been assessed in female soccer players at four different time points across the menstrual cycle (two testing sessions in the follicular phase and two testing sessions during ovulation) and no significant findings related to performance were reported.[29]

Average foot strike value minimally changed during asymptomatic and symptomatic runs. Foot strike changes may occur due to an individual seeking to improve running economy[31] or to reduce risk of injury[32]. In a distance race situation, rearfoot strike has been found to be the most common foot strike type.[33] A systematic review and meta-analysis recently looked at prevalence of foot strike patterns, changes to foot strike with increased running distance, and potential impact on performance.[34] When a runner's foot strike was compared at the start of their race to the end, 11% of runner's foot strike would trend towards a rearfoot strike. It was not anticipated in this study that participants foot strike type would change (i.e., a forefoot runner becoming a midfoot runner), however, all foot strike types were represented among the study participants.

Subjects reported more days running while asymptomatic versus symptomatic. Athletes have previously reported negative perceptions regarding their menstrual cycle.[16] Endurance athletes in India reported improved perception of performance post-menses, however, symptoms were not recorded.[35] Another cohort of runners reported a high volume (91%, n = 195) of experiencing menstrual-related symptoms, yet did not discern if symptoms were experienced on days running or not.[36]

All subjects who participated in this study reported experiencing at least one menstrual cycle-related symptom during data collection. The presence of menstrual cycle-related symptoms has been well documented in other studies that have included team and individual sport athletes[16,23] demonstrating this is a concern across all female sports, and not just endurance runners. A challenge to addressing this concern is the lack of education athletes and support staff may have on the subject.[37] When testing knowledge among professional soccer players and support staff, no group answered correctly on more than half of the questions posed.[37] Another study exploring the perceived knowledge among female athletes, coaches and medical staff reported 40% (n = 433) of the athletes agreed talking about the menstrual cycle in a sport environment is taboo.[38] Barriers to communication around the menstrual cycle can be due to lack of knowledge, interpersonal considerations (e.g., a coach avoiding the topic thinking it would invade the athlete's privacy), or structural (e.g., no organized discussion or opportunities to educate).[39] Educating stakeholders about the menstrual cycle can mitigate taboo around the physiologic process as well as empower athletes to feel in control of their cycle versus being controlled by it.

Limitations

Often runners may have repeated distances they plan to cover during their training window. Due to the heterogeneity of our sample and their training regimens we were unable to explore interindividual differences for similar run distances that may have been categorized as asymptomatic and symptomatic. Total mileage recorded from subjects in our study varied widely. While the sample population was recruited from the same university club running team, participation in team workouts were voluntary. Only fourteen of our twenty-seven subjects had run data eligible for comparative analysis. Because of this, our study was likely underpowered and contributed to our non-significant findings comparing performance outcome variables. Lastly, subjects chose when they did or did not want to run throughout the data collection window. This may have influenced the biomechanical data rendered due to the subject's decision of when to run.

CONCLUSION

Female endurance runners prospectively tracked their training activity in conjunction to reporting menstrual-related symptoms over multiple months. We did not identify significant differences in running gait biomechanic measures captured during runs on symptomatic versus asymptomatic days. Perceived symptom burden was present in this sport population, however, shifting athlete's perception through education may mitigate perceptions around the menstrual cycle and symptoms experienced.

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Figure 1. Total mileage covered by each participant. Those circled in orange were included for comparison analyses.

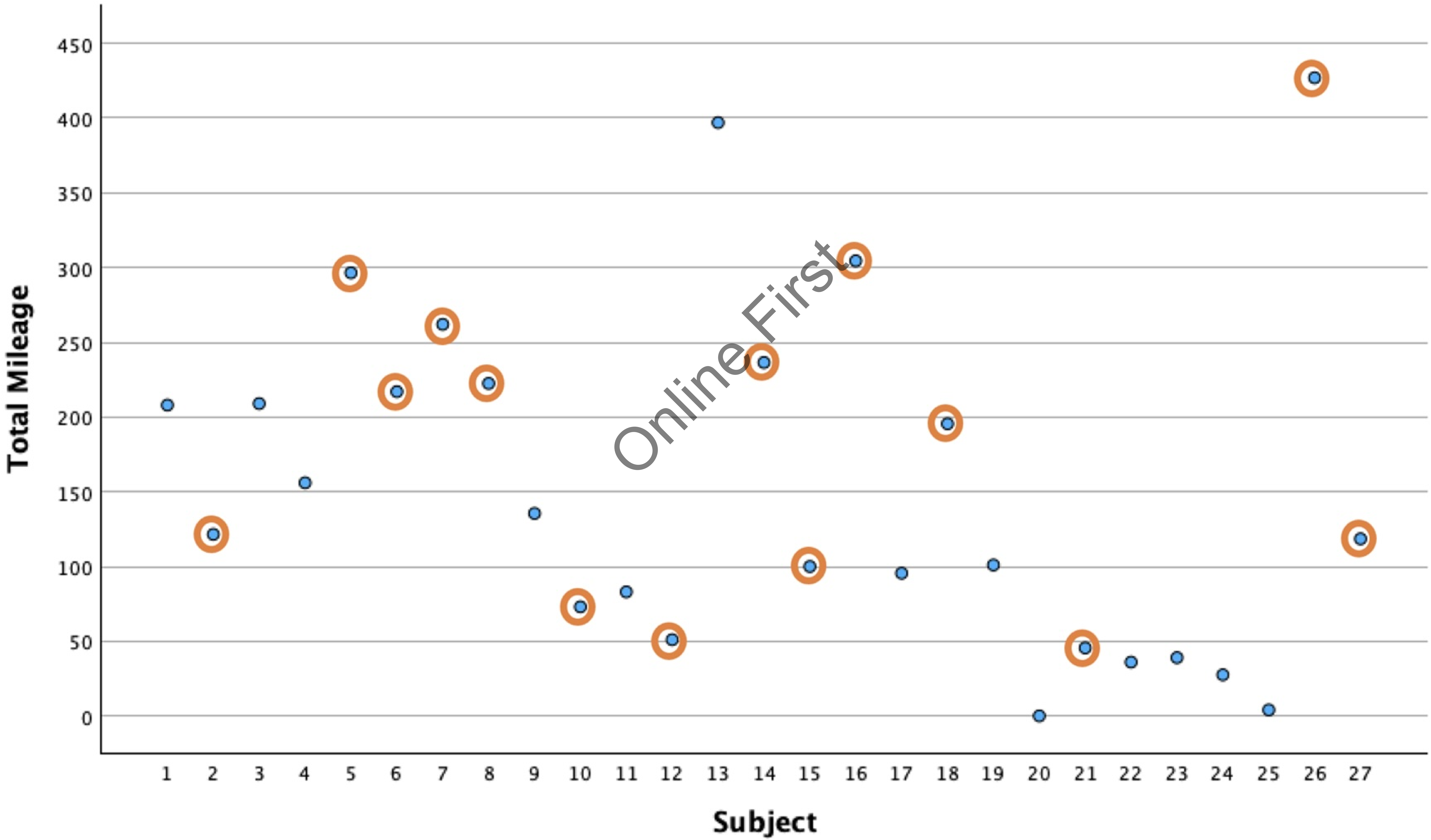

Table 1. Definitions of performance outcome measures.

Category	Variable	Definition
Kinetic	Impact G	Vertical component of peak Gs. Correlates to ground impact force at foot strike.
	Braking G	Horizontal component of peak Gs. Correlates to braking forces at foot strike.
Kinematic	Max Pronation Velocity	Maximum angular rate the foot pronates between foot strike and point of maximum pronation.
	Pronation Excursion	Total range of angular movement when foot pronates from foot strike to maximum pronation.
	Foot Strike Type	Categories are based on the sagittal plane angle of the foot at initial contact;[31] heel (value: 1-5), mid-foot (value: 6-10), or fore-foot (11-15).

Table 2. Subject demographics. BMI – body mass index.

Race/Ethnicity	
White/Caucasian	n=22/27, 81.5%
Multiracial/Biracial	n=3/27, 11.1%
Hispanic or Latino	n=1/27, 3.7%
Asian or Pacific Islander	n=1/27, 3.7%
Age	20.5±2.5
BMI	21.7±1.8
Stress Reaction History	Yes: n=6/27, 22.2%; No: n=21/27, 77.8%

Table 3. Self-reported menstrual cycle characteristics

Menarche	13±1.5
Natural Cycle [Every 21-35 days]	Yes: n=17/25, 68%; No: n=8/25, 32%
Taking Birth Control	Yes: n=10/27, 37%; No: n=17/27, 63%
Birth Control Hormonal	Yes: n=9/10, 90%; No: n=1/10, 10%

Table 4. Running Participation Details

Age Started Running	14±2.1
Self-Reported Competition Level	
College – Club	n=11/27, 40.7%
Competitive Recreational	n=8/27, 29.6%
For Fun	n=8/27, 29.6%
Days Running Per Week	
Two Days	n=1/27, 3.7%
Three Days	n=7/27, 26%
Four Days	n=5/27, 18.5%
Five Days	n=4/27, 14.8%
Six Days	n=9/27, 33.3%
Seven Days	n=1/27, 3.7%
Weekly Distance	
6-15 miles	n=8/27, 29.6%
16-25 miles	n=9/27, 33.3%
26-35 miles	n=6/27, 22.2%
36-50 miles	n=3/27, 11.1%
50+ miles	n=1/27, 3.7%
Running Events	
1 Mile	n=8/27, 29.6%
2 Mile	n=5/27, 18.5%
2K Steeplechase	n=1/27, 3.7%
3K	n=6/27, 22.2%
5K	n=19/27, 70.4%
4 Miles	n=1/27, 3.7%
6K	n=6/27, 22.2%
10K	n=4/27, 14.8%
10 Miles	n=1/27, 3.7%
Half Marathon	n=11/27, 40.7%
Marathon	n=4/27, 14.8%

Table 5. Distribution of Runs by Surface Type

Surface Type	Total Runners	Total Runs Logged (n=850)
Concrete	n=24/27, 88.9%	433, 50.9%
Asphalt	n=25/27, 92.6%	292, 34.4%
Trail	n=16/27, 59.3%	44, 5.2%
Rubber Track	n=10/27, 37.0%	41, 4.8%
Treadmill	n=11/27, 40.7%	33, 3.9%
Grass	n=7/24, 29.2%	6, 0.7%
Wooden Track	n=1/27, 3.7%	1, 0.1%

Table 6. Mean activity frequency

Activity	Asymptomatic Days	Symptomatic Days
Running	22.3±17.1	9.1±7.5
Cross-Training	5.3±9.4	2.4±3.9
Rest / Withheld	15.4±13.9	5.5±5.5

Table 7. Comparison between asymptomatic and symptomatic run days for all subjects.

Comparison – ALL (n=14)	Asymptomatic Mean ± SD	Symptomatic Mean ± SD	Mean Difference ± SD	Effect Size (d)	Significance (p)
Impact G	10.1±2.1	9.7±2.0	0.3±1.3	0.26	0.34
Braking G	7.3±1.2	7.3±1.3	-0.1±0.6	-0.10	0.72
Pronation Excursion (°)	11.5±4.7	12.0±4.9	0.5±2.1	0.24	0.38
Maximum Pronation Velocity (°/second)	562.9±187.6	515.1±289.8	47.9±154	0.31	0.27
Gait Speed (minutes/mile)	9.5±1.0	9.6±1.5	-0.1±1.0	-0.11	0.70
Foot Strike	7.0±3.0	6.7±2.9	0.3±0.8	0.36	0.20

Table 8. Comparison between asymptomatic and symptomatic run days for natural cycle (NC) subjects.

Comparison – NC Only (n=8)	Asymptomatic Mean ± SD	Symptomatic Mean ± SD	Mean Difference ± SD	Effect Size (d)	Significance (p)
Impact G	10.3±1.7	10.1±2.3	0.3±1.1	0.26	0.50
Braking G	7.5±0.8	7.6±1.0	-0.1±0.7	-0.10	0.85
Pronation Excursion (°)	-10.8±5.5	-11.5±5.2	0.6±1.3	0.46	0.23
Maximum Pronation Velocity (°/second)	550.5±131.7	498.9±288.2	51.6±183.3	0.28	0.45
Gait Speed (minutes/mile)	9.4±1.1	9.5±1.9	-0.1±1.3	-0.11	0.76
Foot Strike	6.9±3.2	6.6±2.9	0.3±0.3	0.4	0.29

Table 9. Comparison between asymptomatic and symptomatic run days for subjects taking a hormonal contraceptive (HC).

Comparison – HC Only (n=6)	Asymptomatic Mean ± SD	Symptomatic Mean ± SD	Mean Difference ± SD	Effect Size (d)	Significance (p)
Impact G	9.7±2.7	9.3±1.7	0.4±1.5	0.26	0.56
Braking G	6.9±1.6	6.9±1.5	-0.1±0.5	-0.14	0.74
Pronation Excursion (°)	-12.4±3.8	-12.8±4.8	0.4±3.0	0.12	0.78
Maximum Pronation Velocity (°/second)	579.94±258.1	536.7±318.1	42.9±120.9	0.36	0.43
Gait Speed (minutes/mile)	9.7±0.8	9.7±0.8	-0.05±0.4	-0.12	0.78
Foot Strike	7.1±2.9	6.9±3.2	0.2±0.9	0.27	0.54