



Inefficient impact absorption and reduced shock attenuation in female runners with stress urinary incontinence

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ABSTRACT

Running has been associated with stress urinary incontinence (SUI) in female runners, with prevalence reaching 44 %. Surprisingly, many of these runners exhibit pelvic floor muscle strength and endurance that is similar or even greater compared to continent runners. Therefore, this study aimed to investigate other potential mechanisms associated with SUI in female runners, focusing on impact absorption and muscle function. Thirty-two female runners were divided into two groups: runners with and without SUI. Pelvic floor muscle function was assessed using the Peritron®, whereas the maximum isometric strength of the trunk and lower limb muscles was measured using a portable handheld dynamometer. Kinetic data, including vertical ground reaction force (GRF), energy absorption at the ankle, knee, and hip joints, and shock attenuation between the tibia and femur, were collected using a 3-D motion analysis system on an instrumented treadmill during running. Group comparisons were performed using the Student *t*-test and Mann-Whitney at a 0.05 significance level. There were no differences in pelvic floor, trunk and lower limb muscle function between groups. Despite similar vertical GRF, runners with SUI exhibited lower energy absorption at the ankle ($p = 0.019$; $d = 0.54$), higher energy absorption at the hip ($p < 0.001$; $d = 0.85$) and reduced shock attenuation between the tibia and femur ($p = 0.038$; $d = 0.80$) during running compared to continent runners. Runners with SUI differed in energy absorption and shock attenuation patterns, particularly at the hip and ankle. These findings suggest that incontinent runners exhibit inefficient energy absorption throughout the kinetic chain experiencing greater pelvic demands.

1. Introduction

Stress urinary incontinence (SUI) is a prevalent health condition among sportswomen, characterized by urine leakage during physical activities, such as high-impact exercises, coughing, and sneezing (Cardozo et al., 2023). Repetitive impact during running has been associated with SUI in female runners, with prevalence reaching 44 % (Pires et al., 2020). SUI symptoms significantly affect female runners' participation in sports and overall quality of life, leading to

embarrassment and fear of urinary leakage (Dakic et al., 2021a). Alarmingly, 41 % of female runners reported that their symptoms negatively affect their sports participation, with some even discontinuing athletic activities altogether (Dakic et al., 2021b). Such discontinuation can result in adverse outcomes, including weight gain, decreased energy levels, and social isolation (Dakic et al., 2021a; Dakic et al., 2021b). A deeper understanding of the mechanisms underlying SUI in female runners can provide valuable insights for effective management and prevention, ultimately supporting long-term sports participation

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and improving quality of life.

Pelvic floor structures, including muscles, fascia, and ligaments, increase urethral closure pressure to neutralize impact and intra-abdominal pressure changes (Cardozo et al., 2023). However, during vigorous activities such as running, impact and intra-abdominal pressure can exceed pelvic floor muscle (PFM) tension, causing SUI symptoms (Gan and Smith, 2023). Although incontinent runners show similar or greater PFM strength and endurance (Bérubé and McLean, 2023, 2024; de Melo et al., 2020), they have less passive tissue support (e.g., lower passive stiffness and bladder neck height) than continent runners (Bérubé and McLean, 2023, 2024). Thus, despite similar or greater PFM function, running-induced changes in passive support could lead to urine loss in female runners (Bérubé and McLean, 2023, 2024). Due to the direct tissue connection, accessory muscles such as the abdominal and hip muscles may assist the PFM, could redistribute tension, and reduce PFM overload (Tim and Mazur-Bialy, 2021). However, the role of abdominal and hip muscles in contributing to the continence mechanism is not entirely understood.

During the stance phase of running, ground reaction forces (GRF) can reach up to 2.7 times the runner's body weight (Bennell et al., 2004). The energy generated at initial contact increases body segment acceleration and must be dissipated throughout the kinetic chain (Derrick

et al., 1998). To mitigate this load, the lower limb joints, ligaments and muscles absorb and dissipate forces (Nicola and Jewison, 2012), reducing the impact on the pelvic floor. Imbalances between individual capacity (e.g., muscle function) and task demands (e.g., absorbing impact while maintaining continence) may result in functional overload and contribute to SUI symptoms. The ability to handle task demands relies on local, accessory, and non-local muscles involved in shock attenuation. Some authors suggest that adapting to task demands – such as managing running forces – may be more critical than the impact magnitude itself for performance (Derrick and Mercer, 2004; Fonseca et al., 2020). In this context, difficulty adapting to the mechanical demands of running may impair performance or alter motor control, potentially explaining urinary leakage in susceptible individuals. This study aimed to investigate whether female runners with and without SUI differ in: (1) PFM function; (2) strength of trunk flexors, hip external and internal rotators, quadriceps, ankle plantar flexors; and (3) peak GRF, energy absorption, and shock attenuation. We hypothesized that runners with SUI would present reduced PFM function, lower muscle strength, and impaired impact absorption and shock attenuation during the stance phase of running.

2. Methods

2.1. Participants

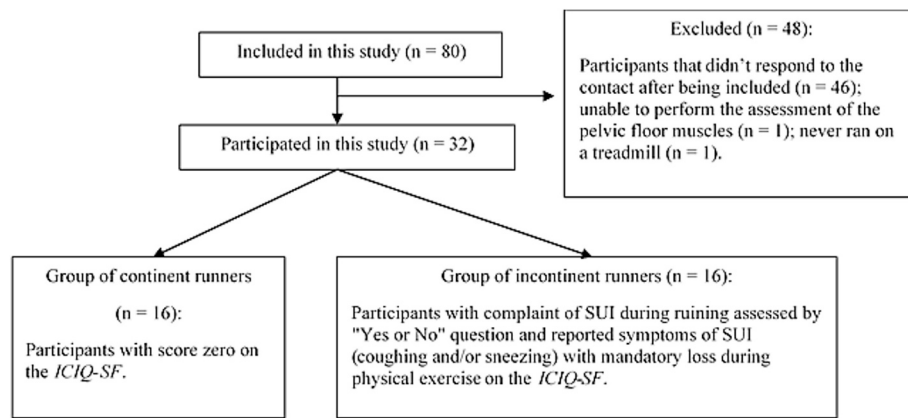
For this cross-sectional study, female runners were recruited through social media and running associations. Data were collected between October 2023 and February 2024 at the Universidade Federal de Minas Gerais (UFMG). Inclusion criteria were: (1) women aged 18–45; (2) ≥ 6 months of running experience, averaging 20 km/week; (3) no lower limbs or pelvic surgery within the last six months; (4) no injury that reduced training for ≥ 7 days or three consecutive sessions, or required medical attention (Yamato et al., 2015); (5) not pregnant or postpartum in the past year; (6) no prior urinary incontinence treatment; and (7) consent to vaginal examination. For the incontinent group (IG), participants had to report SUI while running, confirmed by the *International Consultation on Incontinence Questionnaire-Short Form (ICIQ-SF)* (Tamanini et al., 2004), without urgency incontinence. Although the focus was on SUI during running, participants with occasional leakage during coughing or sneezing ($n = 5$) were not excluded. The continent group (CG) reported no leakage during running and scored zero on the *ICIQ-SF*. Exclusion criteria included inability to run on a treadmill and presence of pain during data collection. Sample size was based on pilot data of vaginal squeeze pressure (cmH₂O) from six runners with SUI (mean 48.32, SD 3.35) and six without SUI (mean 34.59, SD 3.99), using G*Power ($\alpha = 0.05$; $\beta = 0.80$), indicating at least 12 participants per group. Vaginal squeeze pressure was chosen for sample size calculation due to its clinical relevance and literature support. This study was approved by the UFMG Ethics Committee (CAAE: 70329523.9.0000.5149), with informed consent obtained, and followed STROBE guidelines (Von Elm et al., 2008).

2.2. Procedures

Participants first completed an online form covering sociodemographic and clinical details, including age, body mass index, obstetric and sports history, and urinary incontinence characteristics in the IG. The *ICIQ-SF* was used to categorize participants and to complement self-reported urinary loss. Codes consisting of the participants' initials, followed by the month and the last two digits of their year of birth, were employed to ensure anonymity and maintain blinding during data collection and statistical analysis. Two researchers (LNJ and SIRR) handled participant inclusion, characterization and data tabulation while data collection (PFM strength and endurance, maximal isometric strength tests, and running kinetics) and statistical analysis was performed by the principal researcher (NCC). The criteria for selecting



Fig. 1. Marker model used for collecting running biomechanics data: 1 – head of the second metatarsal; 2 – head of the fifth metatarsal; 3 – lateral malleolus; 4 – calcaneus; 5 – tibial tuberosity; 6 – lateral epicondyle of the femur; 7 – patella (1 cm above the superior border of the patella); 8 – anterior superior iliac spine; 9 – sacrum (midpoint between the left and right posterior superior iliac spines); 10 – spinous process of the twelfth thoracic vertebra (T12); 11 – spinous process of the second thoracic vertebra (T2); 12 – jugular notch; 13 – acromion; 14 – lateral epicondyle of the humerus; 15 – medial epicondyle of the humerus; 16 – styloid process of the ulna; 17 – styloid process of the radius; 18 – base of the index finger; 19 – glabella; 20 – tragus of the ear. A – anterior view; B – posterior view.



Flowchart depicting the progression of all participants throughout the study. SUI = stress urinary incontinence; ICIQ-SF = the International Consultation on Incontinence Questionnaire - Short Form.

Fig. 2. Flowchart depicting the progression of all participants throughout the study. SUI = stress urinary incontinence; ICIQ-SF = the International Consultation on Incontinence Questionnaire – Short Form.

muscle groups included being part of the PFM (strength and endurance) (Frawley et al., 2021), having direct tissue connections with PFM (hip external and internal rotators, and trunk flexors) (Tim and Mazur-Bialy, 2021), and participating in energy absorption during the stance phase of running (ankle plantar flexors and quadriceps) (Nicola and Jewison, 2012; Novacheck, 1998).

Intra-rater reliability for PFM strength, endurance, and maximal isometric strength tests was assessed in 12 women over two sessions, seven days apart, in a previous pilot study. Intraclass correlation coefficients (ICCs) were excellent for all muscles, rang from 0.88 to 0.99 (see Supplementary Materials 1 and 2). PFM strength and endurance were measured using Peritron® (CardioDesign, Australia), a validated tool (Ferreira et al., 2011; Rahmani and Mohseni-Bandpei, 2011). Strength was defined as peak vaginal squeeze pressure during a maximal voluntary contraction (MVC); three MVCs were recorded with 30-second rests, and the mean was used for analysis (Frawley et al., 2021). Endurance was measured as the duration a contraction was maintained above 60 % of MVC, based on three trials with 30-second rests (Frawley et al., 2021). Contractions involving the Valsalva maneuver or synergistic muscle use were discarded to avoid confounding PFM assessment. Standardized verbal instructions were given to all participants (Frawley et al., 2021).

A handheld dynamometer (E-lastic, Brazil) measured the isometric maximal strength of the hip external and internal rotators, trunk flexors, ankle plantar flexors, and quadriceps. Details are in “Supplementary Material 2”. After one familiarization repetition, the participants performed three 5-second MVCs with 30-second rest intervals. The mean value was used for analysis. Standardized verbal encouragement was provided. The muscle strength values, measured in newtons, were multiplied by the perpendicular distances (in meters) from the dynamometer’s position to the joint axis during each test and then normalized by the participant’s body mass, resulting in values expressed as Nm/kg.

Kinetic data were collected using an eight-camera 3D motion analysis system (Oqus 7, Qualysis, Sweden) at 300 Hz and a Bertec instrumented treadmill (Bertec, OH, USA) at 1200 Hz. Based on a 5-second static trial, a rigid body model was used to determine segments’ positions with six degrees of freedom. Foot, shank, thigh, pelvis, trunk, arms, and head movements were tracked using 35 reflective markers (Fig. 1) (Wu et al., 2002). Participants ran for 30 min, with data collected in the 30th minute at a standardized speed of 3.3 m/s (Santos et al., 2023). Data were collected at the 30th minute, as the training duration typically ranges from 30 to 60 min, and women commonly report urinary leakage occurring in the middle or towards the end of their sessions (Carvalho

et al., 2018). This fixed speed was set based on a previous study (Santos et al., 2023). All participants wore their own clothing and non-minimalist running shoes.

2.3. Data reduction

The mean values of PFM strength and endurance during the MVC, as well as the mean isometric MVC values of trunk and lower limb muscle groups, were used to compare muscle function between groups.

Kinetic data of the dominant lower limb, determined by the foot used to kick a ball, were analyzed during the stance phase. The inverse dynamics method was applied using force platform data. Segment inertial properties were estimated based on mass, radius, center of mass, and 3D shape (Hanavan, 1964). Linear acceleration was calculated from the movement of the center of mass of each body segment (pelvis, thighs, shanks, and feet), obtained through a 3D motion capture system.

Kinetic and kinematic data were processed using Visual 3D software (C-Motion, Inc., Rockville, MD, USA). Force platform data and marker displacement were filtered using Butterworth fourth-order low-pass filters (cutoff at 20 Hz) (Winter, 2009). Heel-strike and toe-off events were detected in Visual 3D using vertical ground reaction force (threshold: 10 N). The Cardan sequence used was mediolateral (i.e flexion/extension), anteroposterior (i.e abduction/adduction), and longitudinal axes (i.e internal/external rotation). Joint power in the sagittal plane was computed for the ankle, knee, and hip. The data were normalized to 101 points, representing each percentage of the stance phase.

Lower limb joint power was calculated by multiplying the net joint moment (normalized to body mass) by angular velocity at the hip, knee, and ankle in the sagittal plane (Baggaley et al., 2020). Joint energy absorption was defined as the time integral of negative power values during the stance phase (Baggaley et al., 2020). GRF peak was the highest vertical force during stance of the dominant limb. Statistical Parametric Mapping (SPM) was used to assess group differences in vertical GRF across the stance phase.

Shock attenuation reflects changes in high-frequency accelerations between distal and proximal segments, providing insights into the contributions of active and passive mechanisms (Derrick et al., 1998; Derrick and Mercer, 2004; Hamill et al., 1995). Shock attenuation was computed by calculating the power spectral density (PSD) of tibia and femur accelerations during the running stance phase, focusing on the high-frequency range (9–20 Hz) associated with impact (Napoli et al., 2022). The transfer function used was:

Table 1

Characteristics of the participants, muscle function and results of the comparisons between groups (n = 32).

	Group of continent runners, n = 16, mean (SD)	Group of incontinent runners, n = 16, mean (SD)	Group difference: p-value	Effect size Cohen's
Age (Years) ^a	30.38 (5.79)	33.63 (8.35)	0.211	0.46
Height (Centimeters) ^a	161.87 (6.56)	163.37 (5.51)	0.248	0.25
Mass (Kilograms) ^a	59.15 (5.63)	62.62 (9.19)	0.456	0.46
BMI (kg/m ²) ^a	22.59 (1.93)	23.36 (2.26)	0.307	0.37
Number of pregnancies ^b	0.38 (1.08)	0.69 (1.19)	0.262	0.27
Running experience (months) ^b	53.94 (44.65)	73.19 (73.36)	0.497	0.32
Weekly training frequency (days) ^b	3.38 (0.95)	3.75 (1.12)	0.293	0.36
Weekly distance (kilometers) ^b	26.44 (5.31)	28.75 (11.03)	0.831	0.27
ICIQ-SF score ^c	–	7.18 (3.29)	–	–
Frequency of urine lost (n/%) ^c				
Once a day	–	2 (12.5%)	–	–
Once a week	–	4 (62.5%)	–	–
Two or three times a week	–	10 (25.0%)	–	–
Amount of urine lost (n/%) ^c				
A small amount (drops)	–	16 (100.0%)	–	–
Pelvic floor muscle function				
Peritron^a				
Vaginal squeeze pressure (cmH ₂ O)	32.37 (21.00)	42.75 (15.59)	0.123	0.56
Endurance (seconds)	7.86 (10.08)	9.88 (4.72)	0.057	0.40
Isometric maximal strength (Nm/Kg)^a				
Hip external rotators	0.88 (0.34)	1.03 (0.31)	0.124	0.56
Hip internal rotators	0.76 (0.29)	0.80 (0.34)	0.718	0.13
Trunk flexors	1.42 (0.48)	1.55 (0.41)	0.442	0.28
Ankle plantar flexors	1.01 (0.28)	1.09 (0.26)	0.422	0.29
Quadriceps	2.03 (0.73)	2.37 (0.57)	0.162	0.51

^a student's t-test for variables with normal distribution; ^bMann-Whitney test for variables with non-normal distribution; ^c Values are presented as frequency and percentage only for the group with urinary incontinence symptoms. N = number of participants; SD = standard deviation; BMI = body mass index; ICIQ-SF = International Consultation of Incontinence Questionnaire Short Form; Nm = Newtons.

$$\text{Amplitude} = 10 \times \log_{10} \left(\frac{\text{PSD}_{\text{femur}}}{\text{PSD}_{\text{tibia}}} \right),$$

where $\text{PSD}_{\text{femur}}$ and $\text{PSD}_{\text{tibia}}$ represent the PSD of the femur and tibia, respectively. Shock attenuation was defined as the sum of all negative amplitudes in the high-frequency range (Hamill et al., 1995; Napoli et al., 2022). These values between the tibia and femur reflect the energy reaching the pelvis and the demand on its structures. The MATLAB routine used is in the Supplementary Material 3.

2.4. Data analysis

Muscle function, joint energy absorption, vertical GRF peak, and shock attenuation were tested for normality (Shapiro-Wilk), and homogeneity of variance (Levene's test). Energy absorption at the ankle, knee, and hip was compared between the IG and CG, along with the entire GRF curve to capture force distribution over stance duration. Independent Student's t-tests or Mann-Whitney tests were applied according to data distribution. GRF curves were compared using SPM and an independent t-test (<https://www.spm1d.org>) (Pataky et al., 2013). Normality and outlier analysis were performed to ensure data reliability; no statistically significant differences were found in any outcome. Corresponding 95 % Confidence Intervals (CI) were calculated. Effect sizes (d) were classified as small (0.2–0.49), medium (0.5–0.79), or large (≥ 0.8) (Cohen, 1988). Analyses were performed using MatLab R2022a and JASP (v0.18.3) with $\alpha = 0.05$.

3. Results

3.1. Participants

An initial sample of 80 female runners was included in the study. Forty-six participants did not respond to data collection requests, one could not undergo PFM assessment, and one lacked treadmill running experience (Fig. 2). Thus, 32 women (IG = 16, CG = 16) participated in the study. No significant differences were found between groups in age, body mass index, number of pregnancies, running experience, training frequency and distance (Table 1).

3.2. Muscle function

No significant differences were found between the groups in vaginal squeeze pressure, PFM endurance, or isometric strength of hip external/internal rotators, trunk flexors, ankle plantar flexors, and quadriceps (Table 1).

3.3. Running kinetics: Vertical GRF, joint energy absorption, and shock attenuation

Vertical GRF peak or GRF curves did not differ between groups (Fig. 3A). However, runners with SUI exhibited lower ankle energy absorption, higher hip energy absorption (Fig. 3B), and reduced shock attenuation between the tibia and femur during stance (Fig. 4) compared to the continent group (Table 2).

4. Discussion

We aimed to investigate whether female runners with and without SUI differ in PFM function, lower limb and trunk muscle strength, and running kinetics, including peak vertical GRF, energy absorption, and shock attenuation. We hypothesized that runners with SUI would show reduced PFM function, lower muscle strength, and impaired ability to absorb and attenuate impact forces during running. Contrary to our hypothesis, no significant differences were found between groups in PFM strength or endurance, nor in the isometric strength of trunk flexors, hip rotators, quadriceps, or ankle plantar flexors. Likewise, no between-group differences were observed in peak vertical GRF or GRF curves. However, women with SUI showed decreased ankle energy absorption, reduced shock attenuation between the tibia and femur, and increased hip energy absorption during the stance phase of running compared to continent runners. These preliminary results suggest that, despite similar muscle strength and vertical loading, women with SUI may have a diminished ability to effectively absorb and manage the mechanical loads transmitted through the lower limb kinetic chain during running.

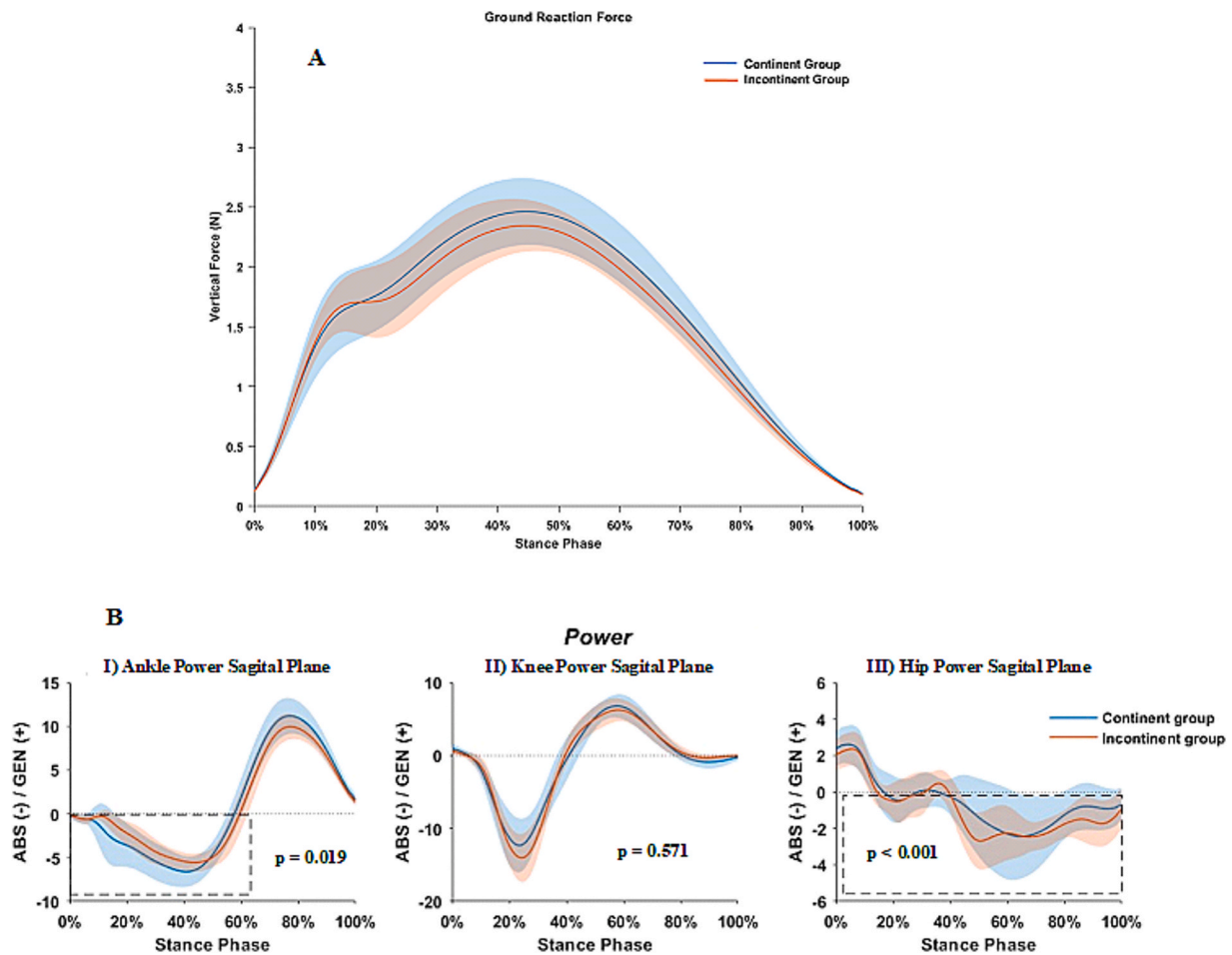


Fig. 3. (A) Vertical ground reaction force during the stance phase of running on the dominant limb, reported in Newtons, with a comparison of vertical ground reaction force curves between groups using Statistical Parametric Mapping. (B) Differences in joint energy absorption between groups of female runners with and without stress urinary incontinence derived from each negative data point during the stance phase at ankle (BI), knee (BII), and hip joints (BIII). Red lines – Group of incontinent runners; Blue lines – group of continent runners. N=Newtons; ABS: absorption; GER: generation.

4.1. Muscle function

While weaker PFM are typically associated with urinary incontinence (Bo and Sherburn, 2005), this may not apply to runners. We found no significant differences in PFM strength or endurance between female runners with and without SUI, aligning with previous studies (Bérubé and McLean, 2023; de Melo et al., 2020). In fact, some data suggest incontinent runners may have comparable or superior PFM performance in isolated tests (Bérubé and McLean, 2023, 2024). This supports the notion that PFM capacity alone may not fully explain continence in dynamic contexts. During running, PFM activation depends not only on strength but also on coordination with other muscle under impact and acceleration demands. Women with SUI may show delayed PFM activation in dynamic tasks, impairing pelvic control (Moser et al., 2018). Our findings align with this: inefficient impact attenuation may increase energy transfer to proximal segments, raising mechanical demands and challenging PFM coordination – even when strength appears normal. This may help explain leakage during high-impact activities like running.

Although no significant group differences in lower limb muscle strength were found, small-to-moderate effect sizes suggest possible clinical relevance, potentially limited by statistical power. This may also reflect preserved muscle function due to regular training in both groups. Other factors – such as eccentric strength, neuromuscular activity, joint range of motion, and flexibility – may contribute to the biomechanical differences seen in runners with SUI and warrant further investigation.

4.2. Running kinetics: Vertical GRF, joint energy absorption, and shock attenuation

Running involves repetitive impacts transmitted from the foot and ankle to the knee, hip, and pelvis (Nicola and Jewison, 2012; Novacheck, 1998). Ideally, the foot and ankle absorb much of this load, especially through the subtalar joint, reducing stress on proximal segments (Nicola and Jewison, 2012; Novacheck, 1998). Reduced foot flexibility and lower distal shock attenuation have been associated with urinary incontinence (Nygaard et al., 1996; Sorriquetta-Hernández et al., 2020). In our study, runners with SUI showed lower shock attenuation between the tibia and femur and increased energy absorption at the hip, suggesting that insufficient energy absorption at the ankle may lead to higher proximal load transfer. This aligns with our joint energy absorption findings. Although our initial focus was on impact attenuation, we analyze energy absorption across the entire stance phase to capture compensatory patterns. As illustrated in Fig. 3B, ankle absorption was reduced early in stance, while hip negative work increased later, possibly reflecting compensatory demands on proximal joints. Evaluating energy absorption over the full stance phase allows a more integrated understanding of how early deficits influence downstream joint mechanics and running efficiency.

Although GRF magnitudes were similar between groups, more energy might have reached the pelvic region in runners with SUI due to inefficient energy dissipating mechanisms, placing greater demands on their pelvic structures. This increased energy reaching the pelvic region

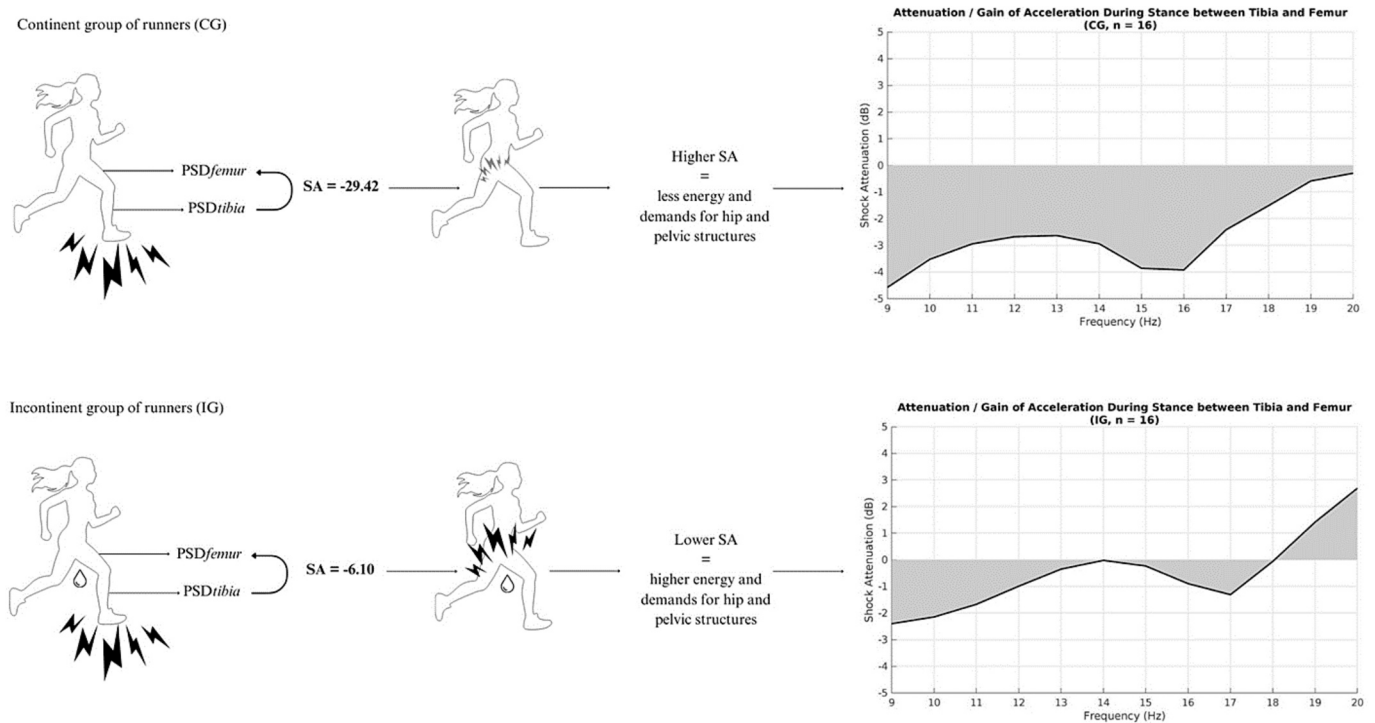


Fig. 4. Comparison of shock attenuation between the tibia and femur during the stance phase of running in female runners with and without urinary incontinence. Resultant accelerations at the tibia and femur were normalized to percent stance. The Welch’s power spectral density estimate function in MatLab (pwelch) was used. The normalized acceleration profiles were converted into power spectral densities, from which high signal power values were computed. Finally, with the transfer function, these power spectral densities were used to derive the shock attenuation occurring between the tibia and femur. These values reflect the energy reaching the pelvic region and the demand on pelvic structures to dissipate it. PSD = power spectral density; SA = shock attenuation; IG = incontinent group; CG = continent group; dB: decibels.

Table 2

Vertical ground reaction force peak, joint energy absorption at the ankle, knee, and hip and shock attenuation between tibia and femur (n = 32).

	Group of continent runners, n = 16, mean (SD)	Group of incontinent runners, n = 16, mean (SD)	Group difference: p-value	Effect size Cohen’s	Mean between groups difference (95 % CI) Continent minus incontinent
Vertical ground reaction force peak (N)	2.21 (0.22)	2.16 (0.20)	0.463	0.26	0.05 (−0.10 to 0.20)
Ankle^a					
Absorption (−)	−3.46 (2.14)	−2.39 (1.84)	0.019*	0.54	−1.07 (−2.51 to −0.37)
Knee^a					
Absorption (−)	−5.59 (4.56)	−6.22 (5.33)	0.571	0.13	0.63 (−2.95 to 4.51)
Hip^a					
Absorption (−)	−1.42 (0.66)	−1.93 (0.53)	<0.001*	0.85	0.51 (0.08 to 0.94)
Shock attenuation tibia-femur^a	−29.42 (34.50)	−6.10 (25.73)	0.038*	0.80	−23.32 (−45.29 to −1.35)

* p < 0.05; ^a student’s t-test for variables with normal distribution. Ground force reaction was represented in Newtons and was normalized with the person’s mass. SD = standard deviation; N = Newtons.

added to the natural demands for urethral closure, could lead to sphincter deficiency and consequent urine leakage in female runners with SUI. Supporting this interpretation, [Niederauer et al. \(2022\)](#) observed reduced tissue damping in women with SUI at 7 km/h, but not at 10 km/h, suggesting reduced capacity to attenuate low-frequency impact forces. They also found that after 30 min of running, damping decreased further in women with SUI, indicating muscle fatigue and a possible reduction in pelvic tissue responsiveness. This progressive decline may increase susceptibility to leakage under fatigue-related conditions ([Niederauer et al., 2022](#)). Similarly, failure to manage mechanical load may transiently impair PFM function ([Gan and Smith, 2023](#)). It was found that after running, even with adequate PFM function, the demands of running cause transient morphological changes in pelvic structures, such as bladder neck descent ([Bérubé and McLean,](#)

[2023](#)). Moreover, other studies suggested a reduced PFM contractility in 20 % of the women after a training session ([Ree et al., 2007](#)), and urinary incontinence symptoms, particularly in the middle or end of the session ([Carvalhais et al., 2018](#)). Considering that further research is necessary to better understand these outcomes, our results suggest that the demand reaching the pelvic region, possibly caused by a reduced ability to absorb impact during running, seems to be a critical factor in incontinence in female runners.

4.3. Clinical implications and limitations

Due to the exploratory nature of this study and the lack of alpha adjustment, findings should be interpreted with caution, and future studies with larger samples are needed to confirm these results.

Although we used gold-standard instruments, there are some limitations. In running, shock absorption is achieved mainly by the eccentric action of the plantar flexors and quadriceps muscles. Although the isometric strength of these muscles was not different between groups, their eccentric strength may play a role in shock absorption. We assessed the vaginal squeeze pressure and PFM endurance using a perineometer in the supine position. While reliable, using other instruments, such as ultrasound and electromyography, could provide more detailed insights into PFM structure and function. Moreover, the muscle function measures used in this study do not fully reflect the ability of the PFM to perform during dynamic and high-impact tasks such as running. Assessing PFM forces in a standing position might be more task-specific, reflecting more the load on the PFM during running (Bérubé and McLean, 2023). However, our results align with those of previous studies that evaluated PFM function of runners with the perineometer in the supine position. Although we aimed to include only women whose primary complaint was SUI during running, five participants also reported occasional leakage during coughing or sneezing. While their main concern remained running-related incontinence, the presence of mixed symptoms in some cases may have introduced variability in symptom presentation, which should be considered when interpreting the findings. Despite the small sample size, large effect sizes supported our findings.

5. Conclusion

While PFM, trunk and lower limb muscle function, and GRF were similar between groups, runners with SUI showed reduced shock attenuation between the tibia and femur, and lower joint energy absorption at the ankle compensated by increased energy absorption at the hip. These preliminary findings suggest that female runners with SUI may experience greater mechanical demands on pelvic structures, likely due to a reduced capacity for impact absorption during running. Given the cross-sectional design of this study, do not imply causation. Further longitudinal and experimental studies are needed to better understand the complex interactions between individual capacities, running demands, and the presence of SUI.

Ethical Approval Information

This study was approved by the Ethical Research Committee of Universidade Federal de Minas Gerais (number 70329523.9.0000.5149).

CRedit authorship contribution statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jbiomech.2025.112753>.

Data availability

Data will be made available on request.

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