

Mechanisms Underlying Running-Induced Stress Urinary Incontinence in Female Runners

by

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Preface

This research was approved by the University of Ottawa Health Sciences and Sciences Research Ethics Board (Appendix A), indicating compliance with national ethical standards for the conduct of human research (H-06-18-759) and with COVID-19 safety precautions (Appendix F). Marie-Ève Bérubé, the doctoral candidate and physiotherapist completing this dissertation participated in all aspects of the study conceptualization, design, data collection, data analysis and interpretation, and the presentation of the results. The work presented in Chapters 3 to 6 have all been published in scientific journals. The results from Chapters 3 and 4 have been presented as podium presentations at the International Continence Society 2023 conference in Toronto. The abstracts for these conference presentations are published in *Continence*, the journal of the International Continence Society. The results from Chapters 5 and 6 have been sent to the International Continence Society 2025 conference.

Contribution of Collaborators

In compliance with the University of Ottawa Academic Regulation C-7 for theses, the contributions of the collaborators involved in the research process are outlined below.

Marie-Ève Bérubé was the primary author of all chapters included in this dissertation. Under the mentorship of her supervisor, Dr. Linda McLean, Ms. Bérubé was fully involved in the conception and design of this study and was primarily responsible for collecting data, analyzing data, and originally drafting important intellectual content for the published content.

This thesis covers a narrative review of the literature in Chapter 2 and content from published publications (Chapter 3, 4, 5, and 6). For the first (Chapter 3) and second (Chapter 4) studies, the co-authors were Ms. Bérubé and Dr. Linda McLean. Ms. Bérubé was primarily responsible for originally drafting important intellectual content and both authors contributed to the revision process and provided final approval prior to this submission. For the third (Chapter 5) and fourth

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Abstract

Background: Some females experience urinary incontinence primarily during exercise and the pathophysiology underlying this form of leakage remains poorly understood. Urine leakage during exercise is a barrier to physical activity and many females restrict and avoid their physical activities due to these symptoms. There is a need to better understand what the short- and long-term effects of running are on pelvic organ support to guide the development of interventions that mitigate urine leakage.

Objectives: The main objectives were (i) to determine whether differences exist in the pelvic floor morphometry and function among females who experience running-induced stress urinary incontinence compared to their continent counterparts, (ii) to evaluate whether changes in pelvic floor morphometry or function occur after an acute bout of running, and whether these changes differ between females who do and do not leak urine while running, (iii) to investigate the feasibility of measuring pelvic floor loading exposure during running, and (iv) to evaluate whether the exposure of the pelvic floor to higher loads during running is associated with greater changes in pelvic floor morphometry or function after a run.

Methods: This thesis involved a single cross-sectional, observational study which addressed all four objectives. Female runners with and without RI-SUI underwent ultrasound imaging to measure their urogenital morphometry and intravaginal dynamometry to assess pelvic floor muscle function. These measures were repeated after an acute bout of running. During the 37-minute running task, a sensor placed in the posterior fornix and an accelerometer placed over the lateral iliac crest were used to infer pelvic floor loading.

Results: There appear to be deficits in pelvic floor passive support in runners with RI-SUI that may predispose them to urine leakage while running. Although an acute run reduced pelvic organ support in all runners, pelvic floor muscle function remained largely unchanged. The observed changes appear to be unrelated to the magnitude of pelvic floor loading experienced during the run. However, because of high variability in pressure measured by the sensor in the posterior fornix, future research should seek out other ways to study how running mechanics may affect pelvic floor loading.

Conclusion: This work described in this thesis is original. It is the first to comprehensively assess intrinsic pelvic floor characteristics concurrently with pelvic floor loading exposure in runners with and without running-induced stress urinary incontinence, concurrently using state-of-the-art measurement tools including ultrasound imaging, intravaginal dynamometry, a posterior fornix pressure sensor, and a wearable accelerometer. These combined findings challenge current assumptions that urine leakage during running is a consequence of the magnitude of pelvic floor loading experienced while running, and points towards passive support deficits as key contributors to urine leakage. This thesis lays important groundwork for future research on the cause of athletic incontinence. Long-term studies are especially needed to explore how running affects pelvic floor health over time. These insights will ultimately lead to interventions which reduce fear of leakage and empower female runners to continue to participate in their chosen sport.

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Abbreviations

2D	Two-dimensional
3D	Three-dimensional
4D	Four-dimensional
ANOVA	Analysis of variance
AP	Anteroposterior
ARA	Anorectal angle
BMI	Body mass index
BN	Bladder neck
CI	Confidence interval
CSA	Cross-sectional area
EMG	Electromyography
GRF	Ground reaction force
ICIQ-B	International Consultation on Incontinence Questionnaire-Anal Incontinence Symptoms and Quality of Life
ICIQ-FLUTS	International Consultation on Incontinence Questionnaire-Female Lower Urinary Tract Symptoms
ICIQ-VS	International Consultation on Incontinence Questionnaire-Vaginal Symptoms
IPAQ	International Physical Activity Questionnaire
IAP	Intra-abdominal pressure

LEAF-Q	Low Energy Availability in Females Questionnaire
LH	Levator hiatus
LP	Levator plate
ML	Mediolateral
MRI	Magnetic Resonance Imaging
MVC	Maximal voluntary contraction
MVM	Maximal Valsalva maneuver
PF	Pelvic floor
PFD	Pelvic floor dysfunction
PFM	Pelvic floor muscle
PFMT	Pelvic floor muscle training
PFSP	Posterior fornix sensor pressure
POP-Q	Pelvic organ prolapse quantification
PS	Pubic symphysis
RI-SUI	Running-induced stress urinary incontinence
SD	Standard deviation
SUI	Stress urinary incontinence
UI	Urinary incontinence
USI	Ultrasound imaging

Chapter 1 Introduction

1.1 Problem statement

Recent systematic reviews and meta-analyses have reported a concerning high prevalence of urinary incontinence (UI) among females¹ from various demographic groups (nulliparous/parous, adolescents/adults) while participating in a wide range of physical activities, with rates ranging from 10.3 to 60.1% (Almoussa & Bandin Van Loon, 2019; Pires et al., 2020; Rebullido et al., 2021; Teixeira et al., 2018). Prevalence appears to vary greatly according to type of physical activity performed (Almoussa & Bandin Van Loon, 2019; Rebullido et al., 2021), reaching between 16% to 44% among females who perform high-impact sports and endurance activities such as running (Hamilton et al., 2023; Pires et al., 2020). The most commonly reported urinary tract symptom among female athletes is described as stress urinary incontinence (SUI) (Hamilton et al., 2023; Pires et al., 2020), which is characterized by involuntary urine leakage experienced during exertion (D'Ancona et al., 2019). Urine leakage experienced during physical activity is a substantial barrier to exercise. A meta-analysis showed that up to one in two females limit their physical activity because of urinary tract symptoms (Dakic et al., 2021). Most often, the females reported that they decreased their activity intensity or avoided provocative activities altogether (Brennand et al., 2018).

Some females with SUI primarily or only leak urine when they exercise, and this form of incontinence is poorly understood. There is an ongoing debate in the literature regarding the impact of exercise on pelvic floor (PF) function. While some advocate that high impact exercise is harmful (Karmakar & Dwyer, 2018), the evidence for harm is scant and some researchers

¹ For the purposes of this thesis, the term "female" refers to individuals who were assigned female at birth. The author acknowledges that individuals may identify with different genders.

encourage females to participate in high intensity training given that causal association is weak (Kruger, 2018). Narrative reviews highlight that this knowledge gap is such that we are unable to draw any conclusions about the role of physical activity in the incidence of pelvic floor dysfunction (PFD) nor the role of chronic exercise pelvic floor muscle (PFM) function and/or pelvic organ support (Bo & Nygaard, 2020; Nygaard & Shaw, 2016a; Shaw & Nygaard, 2017). On one hand, exercise may improve PFM and connective tissue strength, while on the other, it may induce chronic strain and weaken the structures that provide support. Both hypotheses are supported by research findings. Females who engaged in physical activity had a 177% higher risk of reporting urinary incontinence than sedentary females (Teixeira et al., 2018), yet, exercise, when done at mild to moderate intensity, was shown to be protective of the PF and decreased the odds and the risk of experiencing UI (Kim et al., 2022).

1.2 Objectives

It is imperative that we understand the pathophysiology of running-induced SUI (RI-SUI), as it is a key reason why females abandon the very physical exercise that is necessary to maintain or improve their physical and mental health and quality of life. Urine leakage during running is far reaching given that running is an accessible, and popular form of physical activity and it is also an integral component of many other athletic activities and sports. Therefore, the overarching goal of this study was to better understand the mechanisms associated with RI-SUI in females. This research is an essential first step to ultimately improve how RI-SUI is prevented and managed.

The objectives of the research described in this dissertation were (1) to investigate the differences in the morphometry and function of the PFMs among female runners with and without RI-SUI, (2) to evaluate the changes induced by an acute bout of running in the

morphometry and function of the PFMs in female runners who do and do not report RI-SUI, (3) to explore the feasibility of using a pressure sensor located in the posterior vaginal fornix during running to evaluate PF loading and to determine if female runners who experience RI-SUI are exposed to greater PF loading while they run compared to continent counterparts, and (4) to explore the impact of PF loading during running on changes in PF morphometry and function observed after the run.

As such, the primary research questions were:

- 1) Are there measurable differences in PF morphometry (bladder neck height, PF length, levator hiatal area), urethral morphometry (cross sectional area), pelvic landmark displacement (bladder neck and anorectal junction) during maximal contraction and bearing down efforts, resistance of the PFMs to passive stretch, PFM strength or PFM endurance between females who experience SUI while running and females who run but have no history of SUI.
- 2) Do females who experience SUI while running demonstrate larger changes in pelvic morphometry, PF landmark displacement during contraction, resistance of the PFMs to passive stretch, PFM strength or PFM endurance after a standardized running protocol when compared to female runners who do not experience SUI while running?
- 3) Is it feasible to use a vaginal posterior fornix pressure sensor over a standardized 37-minute treadmill run to measure PF loading, and can we use pelvic accelerometry as a proxy measure of PF loading during treadmill running? Do the pelvic floors of female runners who experience SUI while running experience larger loading during running as measured by posterior fornix sensor pressure (PFSP) and/or pelvic accelerations compared to their continent counterparts?

- 4) Are larger PFSPs and/or pelvic accelerations experienced during running associated with greater changes in pelvic morphometry, pelvic tissue displacement during PFM contraction, PFM stiffness, strength and/or endurance after a single bout of running?

This thesis is written as a series of stand-alone articles, followed by an integrated discussion. **Chapter 2** provides an overview of the literature. This review covers the mechanisms underlying continence and the pathophysiology of SUI, with a specific focus on research related to athletic SUI². This review, along with the work of Bo & Nygaard, who identified key areas that are under researched in the field of physical activity and PF dysfunction (Bo & Nygaard, 2020), highlights the need for further research to enhance our understanding of the pathophysiology of athletic incontinence. **Chapter 3** presents a published manuscript that examines the differences in PFM morphometry and function between female runners with and without RI-SUI. **Chapter 4** includes a published manuscript that investigates the impact of a single extended running session on PF morphometry and function among female runners, comparing those with and without RI-SUI. **Chapter 5** details a published study that explores the feasibility of using PFSP to measure PF loading during running. Additionally, it investigates the association between PF loading and RI-SUI in female runners. **Chapter 6** presents a published study examining the relationship between PF loading during running, as measured by PFSP or pelvic accelerations and transient changes in PFM morphometry and function in female runners, as well as evaluating if greater PF loading is associated with more urine leakage among runners with RI-SUI. The integrated discussion is found in **Chapter 7** and summarizes the findings of this dissertation and contextualizes them within what is known about RI-SUI. The knowledge

² We define athletic incontinence as any individual who experiences urinary symptoms because of physical activity beyond the routine activities required for daily living and work. We acknowledge that there are various definitions and terms used to describe athletes, physically active females, female sporting population, etc.

gaps that still exist in the field of athletic incontinence, more specifically RI-SUI, are highlighted to inform future clinical and academic work.

1.3 Contribution to the advancement of knowledge

Keeping in mind that the most frequently reported goal when females seek treatment for SUI is to return to physical activity without urine leakage (Milne et al., 2009), the results of this thesis inform clinical recommendations and practices. While physiotherapy interventions focused on improving PFM strength, endurance, and motor control have high levels evidence as being effective for the management of SUI in general female populations (Dumoulin et al., 2015), the evidence is less strong when pelvic floor muscle training (PFMT) is applied to the athletic population (Demeco et al., 2024; Petter Rodrigues et al., 2024; Rodríguez-Longobardo et al., 2023; Skaug et al., 2024), which may be due to a different pathogenesis than SUI in the general population. Most studies included in these reviews are heterogeneous, have a high risk of bias and dropout rates and small samples.

Recently, a scoping review investigating the attitudes and knowledge of athletes regarding PFD and their engagement with PFMT found that athletes had poor knowledge of PFD and that most of them did not engage in PFMT (Magor et al., 2025). Given that athletes who report adequate knowledge of PFD are approximately 60% less likely to experience them (Cardoso et al., 2018) targeted interventions for this specific population are much needed. By identifying specific markers of RI-SUI, we can advance targeted exercise or biomechanical interventions to better manage athletic incontinence. Effective management interventions to mitigate RI-SUI will empower females to remain active, benefiting their physical and mental health, and their overall quality of life across the lifespan.

Chapter 2 Overview of the literature

In this chapter I provide an overview of the current literature on how continence is maintained in healthy females, along with the multifactorial mechanisms that likely contribute to female SUI. This review presents research that has focused specifically on active females who experience urine leakage during physical activity. I identify key gaps in knowledge that must be addressed, and I lay the groundwork for identifying innovative strategies to treat athletic SUI. Additionally, I highlight the challenges associated with the instruments and methodologies used to assess PFM characteristics and PF loading.

2.1 Maintaining urinary continence

Females maintain urinary continence through a complex interaction of muscles, under the influence of the central and peripheral nervous systems, that work together to ensure the proper storage and the voluntary release of urine. The key structures covered in this review include the urethra, the levator ani muscles and associated connective tissues, and the nervous system. Disruption in one or many of these components can lead to SUI; where leakage occurs when bladder pressure exceeds urethral closure pressure.

The PF is a broad term that encompasses several structures including smooth muscles, skeletal muscles, and connective tissue (Alperin, 2016; DeLancey, 2016). Some PFMs are directly while others are indirectly tethered to the bony pelvis, and all are under the influence of the peripheral and central nervous system. The PFMs will typically fine-tune their activity according to the demands that they are being subjected to, providing graded support to the pelvic structures (Madill, 2016). The main roles of the PFMs are: (1) to support the pelvic organs by resisting caudally directed forces generated by IAP, gravity, and inertial loads (2) to assist in

continence mechanisms such as the control of sphincter activity by keeping or eliminating waste through the urethra and rectum; and (3) to assist sexual function (Alperin, 2016; Barber, 2005).

2.1.1 Urethra

The morphological layers of the urethra, including outer longitudinal and circular urethral striated muscles, the urethral smooth muscles that lie within the striated muscles, the vascular plexus within the mucosa and the connective tissues surrounding the urethra, all contribute to resting urethral closure pressure (DeLancey, 1994a; Kim et al., 1997). The internal sphincter is located at the bladder neck and is composed of smooth muscles, while the thickest part of the external sphincter can be found around the mid-urethra and is composed of striated muscle. Both sphincters allow for voluntary and involuntary control of urine storage (Mistry et al., 2020). The passive structures within the urethra itself such as the vascular plexus within the submucosa are thought to contribute to continence by providing a occlusive pressure via coaptation of the mucosal surfaces (Ashton-Miller et al., 2007). Rud et al (1980) hypothesized that these structures provide intra-urethral pressure to the same extent as closure pressures generated by the striated urethral sphincter and connective tissues supporting the urethra (Rud et al., 1980), forming a dynamic vascular cushion that helps to maintain continence (Jármay-Di Bella et al., 2000).

The urethra is also attached along its length to the anterior vaginal wall and has attachments to the endopelvic fascia, the arcus tendinous fascia pelvis and the levator ani muscles, which provide passive support (Ashton-Miller et al., 2007).

2.1.2 Levator ani

The skeletal muscle components of the PF include the levator ani muscles, the coccygeus, the external anal sphincter, the striated urethral sphincter, and the deep and

superficial perineal muscles (Barber, 2005). As the largest muscle group in the PF, the levator ani muscles play a critical role in providing pelvic organ support. This group of paired muscles can be divided into 3 main components: (1) the pubovisceral (or pubococcygeal); (2) the puborectalis and (3) the iliococcygeal muscles (Ashton-Miller et al., 2007; DeLancey, 1994b), which surround the levator hiatus, which is the opening through which the urethra, vagina and anorectum pass. The mechanical action of a levator ani muscle contraction is dependent on the respective points of origin and insertion of each component. The pubovisceral and iliococcygeal muscles generate a cranial or lifting force and a transverse force that closes the levator hiatus. The puborectalis component mainly contributes, through its horizontal line of action, to closing the levator hiatus (Betschart et al., 2014). The levator hiatus is delimited by the pubic bone (anterior), the levator ani muscles (lateral) and by the perineal body and external anal sphincter (posterior) (Ashton-Miller et al., 2007; DeLancey, 1994b). The urethra, vagina and anorectum, which pass through the hiatus, are compressed against the anterior vaginal wall as a result of the contraction of the levator ani muscles (Ashton-Miller et al., 2007; DeLancey, 1994b). Connective tissue covers both surfaces of the levator ani and forms the pelvic diaphragm.

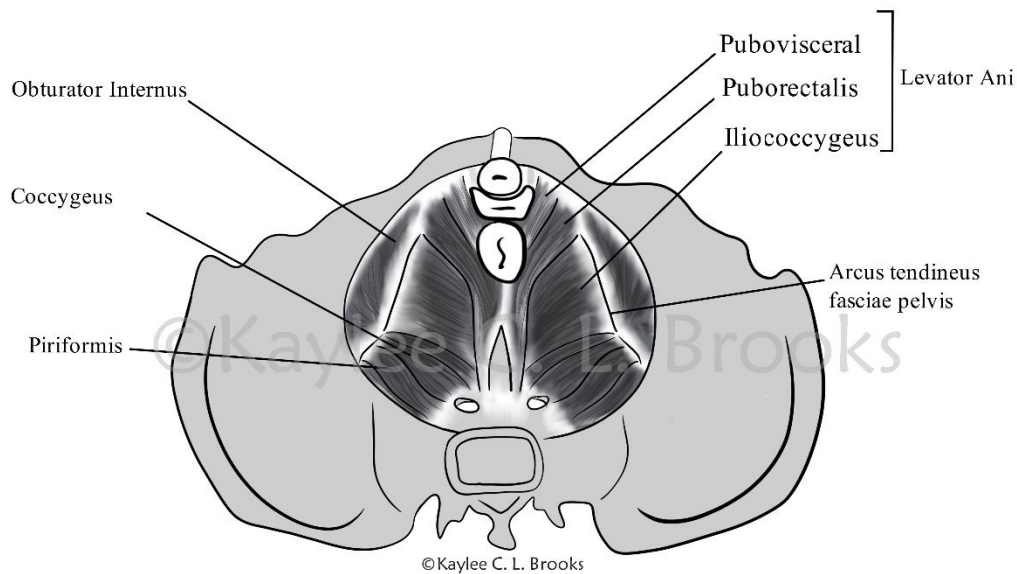


Figure 2.1 Superior view of the deep pelvic floor musculature

2.1.3 The nervous system

The central nervous system, comprised of the brain and the spinal cord, and the peripheral nervous system, including the autonomic and somatic nervous systems, interact to provide innervation to the lower urinary tract and to coordinate PFM activity with bladder storage/micturition (Chancellor & Yoshimura, 2004; Clemens, 2010; Roberts, 2008).

Different regions of the brainstem coordinate the complex interaction between the bladder and urethra, allowing voluntary initiation and inhibition of voiding. The conscious decision to void or delay urination involves cognitive processes that integrate sensory

information from the bladder and the external environment. During the storage phase, there is continuous excitation from the brainstem to the Onuf's nucleus, located in the sacral spinal cord which results in continuous activity of internal urethral sphincter and relaxation of the detrusor to accommodate increasing volumes of urine during the bladder filling phase (Clemens, 2010; Unger et al., 2014). This is modulated through the sympathetic activity of the autonomic nervous system. As the bladder fills with urine, the mechanoreceptors and chemoreceptors in the bladder are activated. The resulting afferent information travels to the pontine micturition center in the brainstem. This activation triggers parasympathetic activity at the sacral level resulting in detrusor contraction with concurrent urethral relaxation for voiding (Clemens, 2010; Unger et al., 2014). This process can be mediated through the prefrontal cortex, which maintains conscious control over urination, allowing one to choose to delay voiding depending on social and environmental contexts (Chancellor & Yoshimura, 2004; Roberts, 2008).

The somatic nervous system provides voluntary control of the striated PFM's via the pudendal and pelvic nerves, which originate from the anterior rami of S2-S4, with much inter-individual variability. It provides motor input to the striated muscles of the PFM's such as the external urethral sphincter and levator ani, allowing voluntary contraction and relaxation. This system provides the final layer of control over continence as well as sensory innervation (Barber et al., 2002; Chancellor & Yoshimura, 2004; Roberts, 2008).

A disruption in any of these structures can result in urine leakage.

2.2 Pathophysiology of stress urinary incontinence in females

The pathophysiology of SUI is complex and remains poorly understood, largely due to the multifactorial nature of the condition (Falah-Hassani et al., 2021; Harland et al., 2023). There

are various interacting components that contribute to the development and severity of symptoms. It is challenging to pinpoint a singular mechanism responsible for the symptoms in each person. The heterogeneity in symptom presentation along with conflicting data on the pathophysiology of SUI, suggest the possibility of phenotypes with different underlying mechanisms (e.g. some females leak only during high-impact exercise and not during activities of daily living).

A recent systematic review and meta-analyses thoroughly evaluated the evidence regarding pathologies underlying SUI (Falah-Hassani et al., 2021) and found several individual factors that are related to SUI. Indeed, the results from the meta-analysis point to defects in the urethral and bladder neck structure and support—females with SUI present with shorter urethrae, bladder neck funneling at rest, lower maximal urethral pressure, and closure pressure (Falah-Hassani et al., 2021). The authors also reported evidence of impaired blood-flow to urethra in females with SUI (Falah-Hassani et al., 2021). In terms of the levator ani muscles, there was insufficient data to perform a meta-analysis, and, while there were inconsistent results, defects of the levator ani appeared to be more relevant to the pathophysiology than weakness or lower endurance (Falah-Hassani et al., 2021).

2.3 Stress urinary incontinence during physical activity

Despite the high prevalence of SUI, many active females may not seek treatment due to the stigma surrounding the urine leakage or the belief that it is an inevitable consequence of their sport or aging. The impacts of SUI during physical activity extend beyond physical discomfort, potentially affecting performance, self-confidence, and quality of life (Culleton-Quinn et al., 2022). Active females with SUI alter their training routines or reduce activity intensity to manage symptoms (Jácome et al., 2011; Salvatore et al., 2009), further emphasizing the

importance of understanding this condition's underlying mechanisms and developing targeted interventions.

The pathogenesis of SUI experienced exclusively during exercise activities remains unclear. Activities like running, jumping, and heavy lifting generate sudden and significant surges in intra-abdominal pressure (IAP) which increase when the vertical load on the body increased (Grillner et al., 1978). IAP refers to the pressure within the abdominal cavity generated by the interaction of the abdominal wall, diaphragm and the viscera (Grillner et al., 1978; Milanesi & Caregnato, 2016). IAP is likely transmitted to the PF as a caudally directed force and may result in urine leakage when the load exceeds the capacity of the PF to support the continence mechanism. The mechanisms contributing to SUI during physical activity are unclear, but a recent conceptual model about athletic incontinence proposes that it likely involves a combination of factors, including insufficient passive support from pelvic structures (such as ligaments and fascia), impaired muscle function, and neuromuscular fatigue caused by repeated impact (Gan & Smith, 2023). When IAP increases and is transmitted to the PF and the urethra, there is a displacement of the bladder neck in the ventrocaudal direction (Dias et al., 2017; Moser et al., 2019; Niederauer, Bérubé, et al., 2022). The PF structures need to absorb and decelerate the caudal displacement of the abdominal and pelvic mass caused by gravity and acceleration. If the surrounding supportive structures are impaired, it would take less force to displace the urethra and cause leakage, however, a modeling study did not show evidence of increased urethral displacement with decreased levator ani stiffness (Dias et al., 2017), suggesting that other passive support structures might be involved. While some may experience urine leakage primarily due to weakened passive support, others might experience leakage due to impaired PFM contractility or altered neuromuscular responses to loading, or both. The degree of PF loading during physical activities, particularly in athletes, might also exacerbate symptoms, yet how PF loading impacts the PF is not well understood.

A recent scoping review highlighted that current treatment approaches to treat PF dysfunctions among female athletes vary greatly and range from preventive, conservation, pharmacological and surgical approaches, but are unfortunately largely based on expert opinion (Giagio et al., 2022). The authors of the review also concluded that given the particular context of active females, the type of training and training volume, the performance level, and other associated disorders should be considered when evaluating PFD in this particular population (Giagio et al., 2022). Using a multidisciplinary approach that combines the expertise of urogynecologists, physiotherapists, dieticians and trainers could be a potential solution to help mitigate symptoms of athletic incontinence, given that it is a multifactorial problem (Rzymiski et al., 2021). However, the variability in symptom presentation highlights the need for individualized approaches in treatment plans and may depend on phenotype.

2.4 The pelvic floor in active females

In 2017, an editorial introduced the concept of «athletic incontinence» to describe urine leakage that occurs predominantly in females during physical activity (Araujo et al., 2017). The authors proposed that the pathophysiology underlying athletic incontinence differs from that of the general population, involving biomechanical factors such as elevated IAP, increased PF displacement, impact forces and muscular fatigue (Araujo et al., 2017). The authors argued that athletic incontinence warrants approaches to evaluation and management that are different from those used for SUI in the general population (Araujo et al., 2017).

2.4.1 Differences in pelvic floor morphometry and function between active females with and without urine leakage

There are conflicting results with regards to comparing PFM morphometry and function between continent and incontinence female athletes/exercisers. The methods that have been used in these studies are varied, including evaluation of voluntary PFM contractile strength, imaging, electromyography and accelerometry.

While some authors report no between-group difference in strength and/or endurance (Bo et al., 1994; Campos et al., 2025; de Melo Silva et al., 2020; Roza et al., 2015a), as measured using digital assessment and/or vaginal manometry, others report that active females have greater strength compared to their continent counterparts (Dos Santos et al., 2019). The study conducted by Bo & colleagues also measured urethral closure pressure and found no between-group differences (K Bo et al., 1994). One study found greater thickness of the levator ani on MRI in athletes with SUI relative to continent athletes, but this was not accompanied by a difference in strength (Roza et al., 2015a). They also reported no difference in the displacement of the PFM on MVC (Roza et al., 2015a), also reflecting that PFM weakness does not seem to be a predominant factor in athletic urinary incontinence.

One group of researchers investigated PF activation during running using an intravaginal sensor on several occasions and has found no evidence of differences in PFM activation (Leitner, Moser, Eichelberger, Kuhn, Baeyens, et al., 2017) or power spectral parameters between continent and incontinent runners (Koenig et al., 2020). A systematic review on PFM activation during high impact activities concluded that there is a reflex activation of the PFMs prior to impact, possibly to counteract the sudden rise in IAP, and that this mechanism seems to be delayed in females who experience symptoms of SUI (Moser et al., 2018). Unfortunately, EMG data collected during physical activity is subject to significant levels of crosstalk and artefacts due to probe movement (Flury et al., 2017; Moser et al., 2018), leading to questions around the validity of these findings.

In terms of PF displacement during running, one study found that during running, prior to heel strike, there was a caudal and anterior rotation of a vaginal probe while after heel-strike, there was a cranial and backward rotation of the probe, with no evidence of differences between continent and incontinent runners (Leitner et al., 2017).

Taken together, these findings suggest that muscle weakness does not appear to be the primary contributor to leakage during exercise, and there might be adaptations that occur to counteract leakage in this population. While reflex PFM activation patterns may play a role in the pathophysiology, the displacement of the PF during running leads us to question the validity of EMG findings. The heterogeneity between measurement techniques, outcomes presented, the body position in which the measurements were taken, and the populations studied (nulliparous/parous, age, physical activity, etc.) are all factors that could contribute to conflicting results.

2.4.2 The acute impact of exercise on the female pelvic floor

Many females report SUI symptoms after repetitive efforts, which could indicate that PFM fatigue is a mechanism at play in athletic incontinence. Only a handful of studies have been published on the acute effects of exercise on the female PF and results are inconclusive. A small (n=12) study suggested that strenuous physical activity could induce PFM fatigue (Ree et al., 2007). After performing a circuit of high impact activities, young, nulliparous females with mild SUI demonstrated a non-significant 20% reduction in their maximal voluntary PFM force-generating capacity, providing some evidence for muscle fatigue as a potential factor contributing to exercise induced SUI (Ree et al., 2007). More recently, a review on the impact of muscle fatigue on SUI in the general active female population reported conflicting evidence. While three studies reported that muscle fatigue was associated with SUI, two studies did not

show any evidence of muscle fatigue (Thomaz et al., 2018). The heterogeneous groups of females studied as opposed to physically active females could explain the conflicting evidence between studies as well as the different methodology used between studies (Thomaz et al., 2018).

Among healthy nulliparous females, Middlekauff et al found that PF tissue lengthening (strain) may be induced through repetitively loading the PF during running (Middlekauff et al., 2016). Despite that some females in their sample reported urine leakage during the running task, there was no investigation of differences between females who leaked and those who did not leak urine. It is not known whether observations of PF tissue strain or PFM fatigue are normally experienced by all females or whether they are implicated in RI-SUI. More recently, de Mendonça et al., 2023 investigated the impact of running on PFM function using a digital assessment technique before and after female runners with and without leakage completed a half-marathon (just over 2 hours of continuous running). The authors reported a decrease in PFM strength and endurance in both groups after the run with no significant between-group differences (de Mendonça et al., 2023). Conversely, a study investigating the acute effect of 60 minutes of heavy weightlifting on the PFM of nulliparous females found no difference in PFM strength, endurance and resting pressure measured using vaginal manometry, nor resting EMG activity after an acute session of heavy weightlifting, suggesting that the PFMs tolerated the activity well in females both with (n=19) and without (n=28) symptoms of SUI (Skaug et al., 2023). Findings of muscle fatigue or strain may depend on the activity, as well as the intensity and duration of the activity.

It is important to acknowledge that most of the studies in which PFM characteristics have been compared among active females with and without SUI were conducted with participants in a supine position. This is a key limitation, as SUI in physically active females typically occurs during upright, high-impact activities such as running, jumping, or lifting. The supine position

does not replicate the functional loading conditions that may contribute to SUI during these activities, potentially leading to an underestimation of the role of PFM function in an active population. It has also been shown that testing position impacts the outcomes measured. For example, studies have found that baseline PFM electrical activity and vaginal pressure measured using manometry are higher in standing than supine (Capson et al., 2011; Gimenez et al., 2022) and that the active and passive tissue properties measured using vaginal dynamometry were also higher in standing (Gimenez et al., 2022), while a meta-analysis reported that the measurements during MVC were similar between positions (Huang et al., 2023).

Additionally, most studies have relied on manual palpation or techniques such as the Pelvic Organ Prolapse Quantification (POP-Q) system, vaginal manometers, or EMG to assess PFM. These methods, although valuable in some contexts, present several limitations that are discussed under section 2.6. Most of these techniques were also applied individually, rather than in combination, which may overlook the complex interactions between different components of PFM function and morphometry before, during, and after exercise.

My thesis research aims to fill these gaps by assessing PFM characteristics in upright, weight-bearing, and dynamically loaded positions that more closely mimics the conditions under which SUI occurs. Combining multiple assessment tools to simultaneously measure strength, endurance, movement, and passive support under dynamic loading provides a more robust understanding of PFM function and morphometry in female athletes and potentially help to guide the development of more effective interventions.

2.5 Running and pelvic floor loading

There is a large body of research around preventing injuries to the musculoskeletal system in runners by modifying running mechanics and improving running economy. Adopting running strategies that can reduce impact forces, accelerations and loading rates at the ankle, knee, and hip could potentially decrease injury rate in the lower limb, however, it remains unclear how altering these components will affect injury rate in the long term (Anderson et al., 2022). The gravitational load, inertial load and IAP experienced during running are likely transmitted to the PF structures, which need to absorb the mechanical load. Unfortunately, there is limited research on running mechanics and the PF. It is plausible that altering running kinetics and kinematics could reduce PF loading and mitigate changes to the PF induced by an acute run.

2.5.1 Acceleration and Ground Reaction Force

Ground reaction force (GRF) is the force that is applied to the body while the foot makes contact with the ground and can be described as a 3D force vector that can be decomposed into a vertical component as well as shear components in the anteroposterior and mediolateral directions that correspond to the acceleration of the body in these respective planes (Enoka, 2008; Perry, 1992; Winter et al., 2009). GRF is derived from Newton's third law of motion, the law of reaction, that states that for every force exerted, there is an equal force of the same magnitude exerted in the opposite direction (Enoka, 2008; Winter et al., 2009). If a force is applied with a large inertia, it will create motion in the direction opposite to this force (Knudson, 2007). To understand how acceleration changes as a function of GRF, we can examine Newton's second law of acceleration represented by the following equation:

$$\sum F = ma$$

where : $\sum F$ is the summation of all forces acting on the body, m is the mass of the body and a is the acceleration of the body's center of mass (Enoka, 2008; Winter et al., 2009). If we assume that someone is doing a vertical jump, the sum of the forces acting on the body would equal the vertical component of the GRF minus the individual's body weight (body mass x gravitational acceleration) (Enoka, 2008; Winter et al., 2009).

The vertical component of the GRF (F_z) contributes to the changes seen in vertical velocity during running. During the non-support phase of the running stride, the vertical force will be 0 BW and the runner will only experience the downward acceleration from gravity, meaning that when the foot makes initial contact with the ground, there will be an opposite, upward vertical force acting on the body (Cavanagh & LaFortune, 1980). The vertical GRF exhibits two peaks during the running cycle—one of 2.2 BW seen at just over 15% of the elapsed contact time, often called impact transient, and a second peak of 2.9 BW occurring later, at around 45% of the elapsed contact time if one uses a rearfoot strike pattern. The second peak is closely related to the end of the absorption phase and the start of the propulsion phase (Cavanagh & LaFortune, 1980). Finally, F_z will drop to zero when the right foot leaves the ground. The anteroposterior component (F_y) of the GRF contributes to the change in forward velocity. During the absorption phase, the F_y is negative at around 0.41x BW and switches back to positive values during the propulsion phase at around 0.47x BW (Cavanagh & LaFortune, 1980). The mediolateral (F_x) component is very small throughout the running cycle at around 0.01BW and is negative during most of the period of contact of the same foot, suggesting that there is a small directed medial force (Cavanagh & LaFortune, 1980). GRFs are likely transmitted up the kinetic chain to the PF, but it remains unclear how the lower limbs attenuate these forces and how they

are transmitted to the PF. Understanding the forces acting on the PF is essential for identifying movement strategies that may reduce PF loading.

2.5.2 Intra-abdominal pressure

It is commonly accepted that IAP is directly transmitted from the abdominal cavity to the bladder (Abrams, 2006). The most direct way to measure IAP is highly invasive and requires access to the peritoneal cavity. A review suggested that the most accurate indirect method to measure IAP is through an intraurethral catheter located within the bladder (Gudmundsson et al., 2002), although it is also possible to measure IAP through the rectal orifice (Abrams, 2006). The latter is still invasive and often requires the participant to stay in a static position. Given that sustained and/or repetitive increases in IAP may contribute to SUI experienced during high impact activities, it is relevant to quantify IAP during such activities. To measure IAP in a real-world setting, one research group has developed a wireless intravaginal pressure sensor that allows the dynamic recording of IAP (Coleman et al., 2012; Y Hsu et al., 2012). A report from the International Continence Society suggests that vaginal recording as a means to estimate IAP could be a more acceptable way to measure this pressure as opposed to using a rectal balloon catheter, yielding comparable recordings (Schäfer et al., 2002). Indeed, once baseline pressures were removed, relative changes in pressure recorded by the wireless intravaginal sensor were highly correlated with changes in pressure recorded by a rectal balloon catheter ($r=0.97$) with a low error of only 1.5 % (Hsu et al., 2012). While this intravaginal sensor has been shown to be valid when used to evaluate IAP during a range of different activities compared to rectal pressures, the authors found that some activities did not produce the same pressure consistently, particularly those that produced higher maximal pressures (Egger et al., 2015). Another group has developed a wireless intravaginal sensor that has demonstrated good

test-retest reliability for mean pressure (Cronbach's α values between 0.943 and 0.955) across a range of different activities, though it has not been validated against a concurrent IAP measurement (Kruger et al., 2013). Under dynamic loading in an upright position, the pressure recorded in the posterior fornix of the vagina likely reflects the combined effects of IAP and the gravitational loading of the pelvic viscera and surrounding structures as well as any additional local tissue pressure (e.g. vaginal wall, cervix). Although not perfect, the use of vaginal pressure sensors allows for indirect measurements of the summed forces acting on the PF during dynamic activities; as such, they have been adopted as a good alternative to rectal balloon catheters or other more invasive techniques (Kruger et al., 2013). Throughout this thesis, I will use the term PFSP to refer to the pressure recorded in the posterior fornix as it offers a more accurate representation of what an intravaginal pressure sensor is measuring.

A healthy PF should be able to withstand different loading conditions without experiencing a PFD.

2.5.3 Pressure and Ground Reaction Force

Little is known about the relationship between PFSP and GRF. An early study by Grillner et al. (1978) investigated intra-gastric pressure recordings with concomitant EMG recordings from the abdominal wall while females walked and ran at different speeds across a force plate (Grillner et al., 1978). They found that an increase in gastric pressure occurred during the vertical loading phase of the body and that abdominal muscle activity occurred just before foot contact (Grillner et al., 1978). More recently, using motion capture technology, Niederauer et al., 2023 found evidence that during 19 activities, hip acceleration and respiration volume as well as flexion moments of the abdomen and thorax explained nearly 60% of the PFSP measured intravaginally (Niederauer et al., 2023). Other factors not captured by the methodology and

model used in this study might account for some of the high unexplained variance in pressure, such as the momentum of the force of the abdominal contents acting on to the PF during movements such as jumping and running. The same group also demonstrated a strong correlation between pelvic accelerations ($r=0.7353$) and peak PFSP measured during walking and concluded that a pelvic-mounted accelerometer could be used as a proxy to estimate IAP (Shaw et al., 2017), however, this was not evaluated during running.

2.5.4 Running biomechanics and pelvic floor

Educators and clinicians in the field of PF physiotherapy are currently exploring strategies to reduce impact forces and modulate loading rate during running to mitigate urinary incontinence symptoms. This is based on the theory that if female runners adopt a running style to reduce impact forces, this will transmit less pressure to the PF and thus reduce leakage. One case study demonstrated that cueing a female runner with urine leakage to «run more softly» over the course of two weeks led to meaningful improvements in her symptoms of SUI while running (Steimling et al., 2023). To our knowledge, only three studies have assessed the relationship between running kinematics and the PFM among female runners. One study did not find any relationships among PFM function, urine leakage and kinematic variables (vertical displacement, knee flexion during loading response and initial foot contact) recorded over a short run (de Melo Silva et al., 2020). More recently, another group explored the relationship between PF symptoms severity using the Australian Pelvic Floor Questionnaire and running kinetics and pelvic accelerations in the postpartum population and reported no associations (Coltman et al., 2025). Finally, a study investigating the biomechanics of runners with and without UI found no differences in GRF during running, nor in trunk, limb and PFM strength between groups (Campos et al., 2025). However, runners with UI demonstrated lower energy

absorption at the ankle and higher energy absorption at the hip with concurrent reduced shock attenuation at the knee, suggesting that the proximal structures such as the pelvis might experience more loading, or that runners with leakage modify their biomechanics in response to their symptoms (Campos et al., 2025).

Using different footwear can alter running mechanics and impact forces (Lin et al., 2022; Sun et al., 2020). A recent study looked at the effects of minimalist versus traditional running shoes on abdominal and lumbopelvic muscle activity among healthy female runners. The authors found no evidence of differences in the EMG activation patterns of the internal oblique, lumbar erector, or gluteus maximus between minimalistic or regular running shoes, however, activation in all muscle groups increased with running speed (García-Arrabe et al., 2022). Foot strike patterns during running may also impact PF loading. Among healthy nulliparous females, Steimling et al.(2024) reported higher PFM activity in runners with a forefoot compared to a rearfoot strike pattern and higher activity with greater vertical displacement while cadence was negatively associated with PFM activity (Steimling et al., 2024). However, as noted previously, recording PFM EMG activity during running might be altered by motion artefacts and noise and should be interpreted cautiously.

Much remains unknown and research is needed to understand the relationship between running mechanics and SUI. Identifying running strategies that effectively mitigate UI symptoms and/or changes in the capacity of the PF to support the pelvic organs may be highly valuable to empowering female runners to train or compete over the long term.

2.6 Challenges with current measurements

Valid and objective measures of PFM function are essential to guide diagnosis and measure treatment outcomes for SUI, however, there are inherent limitations to any tools used to assess PF morphometry and function, which likely involves interactions between muscle strength, endurance, passive support, and neuromuscular coordination. For example, manual palpation is accessible and a low cost tool, however, it lacks the objectivity and the discrimination required to detect small changes in PFM function, and its reliability, particularly inter-rater, is questionable (da Silva et al., 2021; Rai et al., 2023). Vaginal manometry is also an accessible and low-cost tool that can be used to assess PFM function. However, it is an indirect measurement of force and the measurements are made in a static supine position given the influence of IAP on vaginal pressure measurements (Frawley et al., 2006; Rai et al., 2023). While EMG is a valuable tool to assess muscle electrical activity and motor control, it is plagued with motion artefact and crosstalk, particularly during physical activity, and between-day reliability is poor (Flury et al., 2017; Moser et al., 2018; Worman et al., 2023).

PF support can be evaluated using the POP-Q system (Persu et al., 2011), which is again an accessible tool that is low-cost. The limitation of this tool is that it uses an ordinal scale, and this can affect responsiveness to intervention if there were small changes that could not be captured. It has also been reported that there is erroneous and/or incomplete data when used in research in most studies using this outcome measure (Younes et al., 2024). Its intra-rater and between-rater reliability is moderate (Stark et al., 2010) but its validity has been questioned (Ostrzenski, 2021). Testing it in a standing position can be challenging for the assessor but is recommended to observe the maximum extent of pelvic organ support (Visco et al., 2003). As for magnetic resonance imaging, although it provides a detailed visualisation of pelvic structures, its temporal resolution for capturing dynamic movement is limited and issues related to access and cost present additional challenges (Tunn et al., 2003; Worman et al., 2023). Given that many active females experience SUI during high-impact activities, it is crucial

to move beyond traditional, supine-based assessments and explore PFM morphometry and function under more realistic conditions that mimic the stresses imposed on the PF during physical activity.

2.7 Innovations that strengthen the proposed work

This thesis involves four innovations that have allowed us to make major contributions to our knowledge of RI-SUI.

2.7.1 Intravaginal dynamometry

The Motor Function Measurement Laboratory has developed a custom, automated PFM dynamometer that integrates 3D printed arms (single participant use) and high-quality mechanical components. The dynamometer uses computer-driven opening at standardized speeds and apertures and is portable. This allows data collection to occur in different positions (eg. standing). Further, the forces measured by this device are less influenced by changes in IAP when compared to pressure measurement systems used in previous works. Active and passive PFM forces measured by this dynamometer show excellent between trial reliability for maximum force generating capacity (aperture at 35 mm; ICC=0.94-0.96) and peak resistance to passive stretch at both slow (25 mm/s; ICC=0.96-0.98) and fast (50mm/s; ICC=0.95-0.96) speeds of opening (Bérubé et al., 2018), making this an ideal instrument to use in the proposed work.

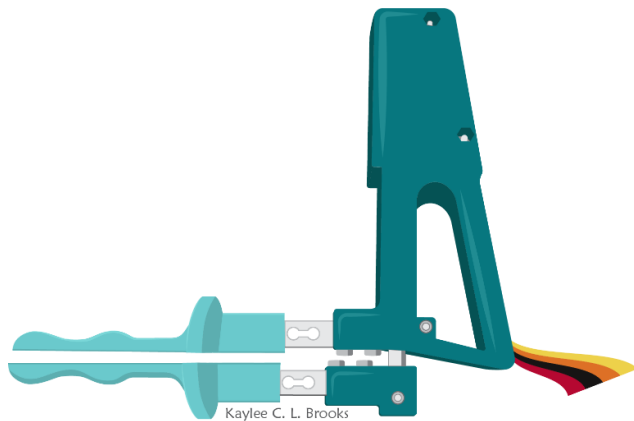


Figure 2.2 Intravaginal dynamometer

2.7.2 Ultrasound imaging

Recent advances in non-invasive imaging of the female urogenital system using transperineal USI have provided several insights into morphological (Dietz, 2013; Dietz, Steensma, & Vancaillie, 2003; Pirpiris et al., 2010) and mechanical (Constantinou, 2016) factors associated with SUI. 2D transperineal USI allows the visualization of the urogenital complex both at rest and during dynamic tasks such as PFM contraction and Valsalva maneuver, providing valuable information about the pathomechanics of SUI (Constantinou, 2016; Dietz, 2013). Further, 3D transperineal ultrasound imaging allows for the visualization of the levator hiatus (Dietz, 2013a), which may be implicated in the pathophysiology of RI-SUI. Our group has already developed significant expertise in the use of transperineal USI to quantify both PFM morphometry (Thibault-Gagnon, Auchincloss, Graham, & McLean, 2018; Thibault-Gagnon, Gentilcore-Saulnier, Auchincloss, & McLean, 2014) and biomechanics (Czyrnyj et al., 2018), having used these approaches in clinical studies (Brooks, 2017; McLean et al., 2013).

2.7.3 Measurement of pelvic floor loading

Our collaborator Dr. R. Hitchcock and his team have developed the intravaginal pressure sensor that measures and streams PFSP data in the field (Rosenbluth et al., 2010). As noted above, this device is reliable and has been validated against the gold standard, a rectal balloon catheter (Rosenbluth et al., 2010; Schäfer et al., 2002). Pilot data collected using this sensor demonstrated that we can clearly distinguish differences in PFSP among running speeds. Using this device in the proposed study provided valuable insights into differences in PFSP, which may be extrapolated to mechanical loading of the PF, between females who leak urine while running and those who do not, while also allowing us to determine whether the pressures experienced during running influence the extent of changes seen in PF morphometry and function after an extended run.

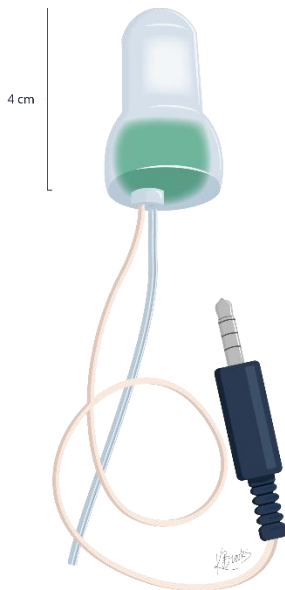


Figure 2.3 Posterior fornix pressure sensor

2.7.4 Measurement of running mechanics using wireless accelerometers

Acceleration values recorded from sensors located at the iliac crest are reliable and valid. Dr. Graham and his collaborators have extensive expertise with the acquisition of biomechanical data using wireless technology. Through innovations in sensor technology and data streaming recently developed in Dr. Graham's laboratory (Graham & Josan, 2017) we were able to stream pelvic acceleration data throughout the running protocol to determine whether pelvic accelerations are correlated with PFSP, and whether the extent of changes in PFM morphometry and function after a bout of running are associated with the magnitude of the accelerations (vertical and magnitude). The acquisition of such data is innovative in the field of urogynaecology and is an essential feature of the proposed study as it may lead to recommendations around interventions focused on changing running mechanics as a means of reducing or eliminating RI-SUI.

2.8 Summary and rationale for current research

The rationale for the current research arises from the need to better understand the complex mechanisms underlying SUI in physically active females, particularly during running, which is a widely practiced and accessible form of exercise that plays a key role in many physical activities. While SUI is a prevalent condition among females engaging in high-impact activities such as running, its precise pathogenesis remains unclear. The current hypothesis regarding the role of physical activity on the PF suggests a dual effect, with both potential benefits and risks depending on the type and intensity of the activity. On one hand, certain physical activities, particularly those involving high-impact movements like running, are thought to increase PF loading and strain on the PFMs, potentially contributing to SUI. The repetitive loading and mechanical stress during such activities may lead to fatigue or weakening of the pelvic support structures, compromising their ability to maintain continence. On the other hand,

physical activity is associated with overall muscle strengthening, including the PFM. Some studies suggest that well-conditioned PFMs in physically active females may provide enhanced support to the bladder and urethra, reducing the risk of SUI. The type, duration, and intensity of exercise seem to play a critical role in determining whether physical activity strengthens or overloads the PF, yet most studies have focused on static assessments of PFMs in supine positions, which do not accurately represent the dynamic, high-impact scenarios where SUI is most likely to occur.

It has been suggested that there may be a training effect or compensatory adaptations in PFMs in female athletes with SUI, but these hypotheses remain largely untested (Gan & Smith, 2023). The current research aims to address this gap by using a comprehensive approach that assesses PFM morphometry and function by using multiple and validated state of the art assessment tools and techniques to capture a comprehensive set of PFM characteristics between incontinent and continent female runners before and after a prolonged run. Assessing the PF in an upright position allows provide insight into the PF when it is being loaded by gravity, offering a more functional assessment that is relevant to running. Additionally, using pelvic accelerometers and a PFSP during running will offer insights into the dynamic loading of the PF and allow the objective exploration of the changes induced to PF morphometry and function during repetitive loading.

This research is critical not only for advancing the basic understanding of how PF mechanics contribute to SUI but also for improving intervention strategies. By identifying the specific factors that differentiate athletes with and without SUI, we can develop more targeted and effective prevention and rehabilitation programs, potentially reducing the high incidence of SUI in physically active populations. This study is particularly relevant for developing tailored interventions that address individual variations in PFM function, passive support structures, and the effects of repetitive loading during exercise.

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Chapter 3 Differences in pelvic floor muscle morphology³ and function between female runners with and without running-induced stress urinary incontinence

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Authors' Contributions statement:

ME Bérubé: Project development, Data collection, Manuscript writing, Revision process

L McLean: Project development, Manuscript writing, Revision process

³ The term *morphology* was used in Chapters 3 to 5; however, *morphometry* is the preferred and more accurate term, which has been adopted in Chapters 1, 6 and 7.

3.1 Abstract

Objective: To investigate the differences in pelvic floor muscle (PFM) morphology and function between female runners with and without running- induced stress urinary incontinence (RI-SUI).

Design: This was a cross-sectional, observational study. **Methods:** Experienced female runners were recruited into two groups: runners who regularly experience RI-SUI ($n = 19$) and runners who do not ($n = 20$). Active and passive pelvic floor muscle (PFM) properties were assessed using intravaginal dynamometry during maximal voluntary contractions (MVC) and during passive tissue elongation. The morphology of the urethra and PFMs was assessed using 2D and 3D transperineal ultrasound imaging. Independent t tests or Mann–Whitney U were used as appropriate to test group differences on all study outcomes, and Cohen's d effect sizes were calculated.

Results: The rate of force development during the MVC was significantly higher in participants reporting RI-SUI ($p \leq 0.05$) and conversely, significantly lower during passive elongation of the PFMs ($p \leq 0.05$) compared to runners with no history of leakage. Concurrently, the extent of bladder neck elevation between rest and maximum voluntary activation was significantly higher among those with RI-SUI compared to those without. Although not significant, small to moderate effect sizes were observed for other outcomes—active force outcomes measured during MVC tended to be higher in runners with RI-SUI, while passive force outcomes measured during passive tissue elongation tended to be lower. The cross-sectional area of the urethral wall and the area of the levator hiatus tended to be larger in runners with RI-SUI compared to those without.

Conclusion: Runners who experience RI-SUI demonstrate better PFM contractile function but lower passive support when compared to their continent counterparts.

KEY POINTS

Findings: Our results point to adaptations in the active properties of the PFMs to enhance pelvic organ support and urethral closure, as well as compromised stiffness of the levator ani and bladder neck support structures among runners with RI-SUI when compared to runners with similar training distances and experience who do not leak urine.

Implications: While runners with RI-SUI appear to benefit from PFM training to improve muscle function and their urinary incontinence symptoms, they might also profit from treatment options that address impaired pelvic organ support, such as pessaries, to mitigate the strain on the passive support structures during running, and consequent urine leakage.

Caution: Our sample consists of middle-aged runners that did not stop running because of their urinary symptoms. The design of the study does not allow any contribution to the debate regarding the impact of exercise on pelvic floor function.

3.2 Introduction

Recent systematic reviews and meta-analyses have reported on the concerning high prevalence of urinary incontinence (UI) in females from various demographic groups (nulliparous/parous, adolescents/adults) doing a wide range of physical activities (Almoussa & Bandin Van Loon, 2019; Pires et al., 2020; Rebullido et al., 2021; Teixeira et al., 2018), with prevalence reaching 44% among females who perform high-impact sports and activities such as running (Pires et al., 2020). The most commonly reported urinary tract symptom among female athletes is described as stress urinary incontinence (SUI) (Pires et al., 2020), which is characterized by involuntary urine leakage experienced during exertion (D'Ancona et al., 2019). Urine leakage experienced during physical activity is a substantial barrier to exercise and up to one in two females limit and restrict the intensity of their physical activity because of urinary tract symptoms (Dakic et al., 2021). This is problematic given that running is an accessible, and popular form of physical activity that is also an integral component of many other athletic activities (triathlon, aerobics, CrossFit®, etc.).

Some females with SUI primarily or only leak urine when they exercise—and this form of incontinence is poorly understood. As with SUI in the overall population, multifactorial components such as neuromuscular damage and structural damage to the urethra, bladder neck, and the levator ani muscles (PFMs) as well as their associated connective tissues are likely implicated (Falah-Hassani et al., 2021). Only a handful of studies have investigated the pelvic floor properties between athletes with and without symptoms of athletic incontinence. While one cross-sectional study reported no significant difference in PFM strength nor endurance between continent runners and runners with SUI (de Melo Silva et al., 2020), another one found that nulliparous athletes with symptoms of SUI and who practiced a variety of sports,

including running, had significantly higher PFM strength than athletes who did not leak urine (Dos Santos et al., 2019). In another study involving a small sample of nulliparous football players, a sport that requires running, incontinent females presented with thicker levator ani muscles at the level of the mid vagina, but no differences were found in the extent of displacement of the pubovisceral muscle during maximal voluntary contractions (Roza et al., 2015b). They also found no differences in PFM strength between the athletes with and without urinary incontinence (Roza et al., 2015b). Overall, results from these studies suggest that adaptative changes may impact the morphology and the function of the PFMs among incontinent athletes, but that the observed changes may depend on the activities performed or on demographic characteristics.

Since running-induced stress urinary incontinence (RI-SUI) is a key reason why women abandon the very physical exercise that is necessary to maintain or improve their physical and mental health and quality of life (Dakic et al., 2021), it is imperative that we better understand the specific pathophysiology of urine leakage during this activity. To our knowledge, no study has concurrently investigated both the morphologic and mechanical differences in the pelvic floor structures between runners who experience athletic incontinence and those who do not. The aim of this study was to investigate differences in pelvic floor morphology and function between female runners who do and do not regularly experience SUI while they run, with a view to improving how RI-SUI in female runners is prevented and managed. We hypothesized that females with RI-SUI would exhibit differences in pelvic morphology and levator ani function when compared to continent runners, shedding light on the pathophysiology of RI-SUI.

3.3 Materials and methods

3.3.1 Design

This cross-sectional, observational case-control study received approval from the local institutional research ethics board. Data collection occurred between June of 2019 and March of 2021, with a gap between March of 2020 and January of 2021 due to laboratory closures related to the COVID-19 pandemic. Using pilot data from the area of the levator hiatus at rest in standing recorded using transperineal ultrasound imaging (USI) from four runners with SUI (mean 20.8 cm²; SD 6.21 cm²) and eight without SUI (mean 15.99 cm²; SD 2.32 cm²), an *a priori* two-tailed power calculation using G*Power (version 3.0.10; $\alpha=0.05$; $\beta=0.80$) estimated that a minimum of 16 runners per group would be necessary to detect between-group differences.

3.3.2 Participants

Runners aged 18 years and older who had female reproductive organs and no known risk factors related to physical activity, as determined by the administration of the Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) (Shephard, 1988) were recruited from the local community through local running groups and physiotherapy clinics. To be eligible, volunteers had to train by running at least 5 km in less than 50 minutes at least twice per week and had to average more than 10km of distance per week, having done so for at least one year. Runners were recruited into two cohorts: those who regularly (≥ 1 per week) experienced SUI while running, and those who did not. Runners who reported leaking at least 2 to 5 times per month while using mitigation strategies (voiding their bladder before/during the run, running slower, avoiding hills, etc.) to avoid leakage were included if they leaked more than once per week when not using these strategies. Participants who reported sporadic episodes of urinary urgency during running, without associated leakage, were not excluded. Runners were excluded if they presented with a history of urogenital surgery or neurological disorders, if they reported symptoms of low energy deficiency as measured by the Low Energy Availability in Females Questionnaire (LEAF-Q) (Melin et al., 2014), if they were pregnant or if they had delivered a

baby within the previous year, if they had a pelvic organ prolapse that was caudal to the hymen on a maximal Valsalva maneuver (MVM) performed in a standing position, or if they experienced pelvic pain to the extent that they were not able to undergo a regular gynaecologic examination. They were also excluded if they reported leakage related to urinary urgency during running. After providing written informed consent, all eligible participants provided demographic information including age, parity, obstetrical history (i.e. vaginal vs Caesarean section, use of forceps) and menopausal status, and were asked to complete the International Consultation on Incontinence - Female Lower Urinary Tract Symptoms Long Form module (ICIQ-FLUTS) (Abrams et al., 2006), the Anal Incontinence Symptoms and Quality of Life module (ICIQ-B) (Cotterill et al., 2011), the Vaginal Symptoms module (ICIQ-VS) (Price et al., 2006) the and the International Physical Activity Questionnaire (IPAQ) (Hagströmer et al., 2006).

3.3.3 Laboratory assessment

The laboratory assessment was performed by the main researcher, who is a registered physiotherapist trained as a pelvic health physiotherapist with over 5 years of experience. Height, weight, and waist-hip ratio were recorded using standardized techniques. Next, participants underwent an intravaginal examination of their pelvic floor in supine using standard bi-digital palpation techniques (Laycock & Jerwood, 2001). If the participant was unable to perform a proper maximal voluntary contraction (MVC) of their PFMs, they received instructions and tactile feedback to ensure that a proper contraction could be performed prior to any data collection. Once a correct PFM contraction could be performed, the participant was also shown and provided with feedback on how to perform a MVM. For the purposes of this study, Valsalva was defined as a bearing down maneuver with concomitant relaxation and caudal movement of the pelvic floor and perineum.

Once ready, the participants underwent a 2D and 3D B-mode ultrasound imaging (USI) evaluation of their pelvis using a GE Voluson S6 system (General Electric, Toronto, Canada). The study physiotherapist first used trans-abdominal ultrasound imaging to standardize estimated bladder volume between 100 to 200mL. If bladder volume was under 100mL, the participant was asked to drink a small amount of water and to wait 20 minutes; if it was over 200mL, the participant was asked to void a small amount to bring the volume within a range of 100-200mL. Once the target bladder volume was reached, in a standardized supine position with the knees bent approximately to 90 degrees, three static 3D volumes of the full length of the urethra were collected using a RIC5-9A-RS endoprobe (4-9MHz, GE Healthcare Ltd., Toronto, Canada) placed at the urethral meatus (McLean et al., 2013; Tooze-Hobson et al., 2001). Next, participants assumed a standardized standing position with their feet shoulder width apart, their knees slightly flexed, and their pelvis just touching an examination table posteriorly to limit postural sway. A series of 2D sagittal plane images and 3D volumes were acquired using a RAB6-RS (2-5 MHz, GE Healthcare Ltd., Toronto, Canada) 3D curvilinear probe placed transperineally. A static 3D volume was acquired of the levator hiatus in quiet standing and dynamic volumes (4D) were acquired while the participant performed the MVM three times (Dietz et al., 2005; Dietz et al., 2011; Majida et al., 2009). 2D ultrasound videos were then recorded during MVM, and MVCs of the pelvic floor muscles (PFMs) (Dietz, 2004; McLean et al., 2016) each performed three times. 2D videos were processed offline using a custom MATLAB code (R2020a) and 3D volumes were processed offline using 4D View® software (GE Healthcare Ltd., Toronto, Canada).

While remaining in a standing position, participants were instrumented with an automated, servo-controlled intravaginal dynamometer. The closed arms were inserted into the vagina, then the arms were opened to an anteroposterior (AP) diameter of 35 mm. Participants were asked to perform three repetitions of the MVC while forces in the mid-sagittal plane were

recorded in Newtons. The participant then returned to the supine position. The dynamometer arms were once again inserted into the vagina, and passive forces were recorded while the AP diameter of the dynamometer arms moved from 15mm to 40mm at a constant speed of 50mm/s. Pelvic floor muscle elongation was held at the maximum (40mm) diameter for 7 seconds to evaluate the stress relaxation response before the arms returned to the closed position. If the participant contracted their PFMs during passive elongation, which was evident as a sharp increase in force on the display screen, the trial was discarded and was repeated. Three repetitions of passive tissue elongation were performed. The validity and reliability metrics for these measures and all details of the standardized procedures can be found in previous publications (Bérubé et al., 2018; Czyrnyj et al., 2021).

3.3.4 Outcomes

The PFM morphologic outcomes captured by 3D USI included the cross-sectional area (CSA) of the urethral wall at the mid-urethra (McLean et al., 2013; Tooze-Hobson et al., 2001), the area, anteroposterior (AP) diameter and mediolateral (ML) diameter of the levator hiatus at rest and on MVM, as well as the difference between these outcomes at rest and at peak MVM (Dietz et al., 2005; Dietz et al., 2011; Majida et al., 2009). Signs of complete and partial levator avulsion were evaluated using the 3D volumes of the levator plate acquired in standing and the techniques described by Dietz et al (Dietz et al., 2008; Dietz et al., 2011). From the 2D USI videos, the bladder neck (BN) height, and levator plate (LP) length at rest, and their relative displacement during the MVC and MVM tasks were measured (Dietz, 2004; McLean et al., 2016). Measures of PFM function acquired through dynamometry included baseline force, relative peak force, and rate of force development achieved during each MVC, and static endurance measured as the time before the peak force achieved during the MVC decreased by 35%. Passive tissue forces measured during elongation included baseline force, relative peak

resistance to passive stretch, rate of force development (stiffness) during passive elongation (Bérubé et al., 2018; Czyrnyj et al., 2021), and the stress relaxation coefficient (SRc). Rate of force development was measured as the highest instantaneous slope observed during elongation (Bérubé et al., 2018; Czyrnyj et al., 2021), while the stress relaxation coefficient was quantified by curve-fitting the data to the equation $y = a * x^b + c$, where b represents the decay coefficient representative of the SRc; more negative values for SRc reflect greater elasticity.

3.3.5 Data analysis

All statistical testing was carried out using IBM SPSS version 28 and $\alpha=0.05$ was used for all tests. All outcomes were tested for normality using the Shapiro-Wilk test, and parametric (t-test) or non-parametric (Mann-Whitney U) analyses were used as appropriate to test group differences between runners with and without RI-SUI, while Chi-Square was used to analyze group differences in dichotomous variables. Due to the exploratory nature of the study, $\alpha=0.05$ was not adjusted based on multiple comparisons. Cohen's d values were calculated for each outcome; $0.2 \leq d < 0.5$ were considered small, $0.5 \leq d < 0.8$ moderate, and $d \geq 0.8$ were considered large (Lee, 2016).

3.4 Results

3.4.1 Sample Demographic Information

Sixty-nine female runners were screened, of which, fifty-nine were eligible and thirty-nine completed the laboratory assessment. Among the 20 potential participants who were deemed eligible but who did not participate, n=13 did not respond to follow-up email after screening, n=2 declined to participate because of the COVID-19 pandemic, n=4 had temporarily stopped running after the screening session or were too busy, and n=1 had a pelvic organ prolapse

beyond the hymen noted on examination (n=1). Twenty runners were included in the control group (i.e. no urine leakage during running), while nineteen were cases (i.e., SUI $\geq$ 1/month during running). The groups were similar in terms of demographic outcomes (**TABLE 1**), however, the controls were slightly younger than the cases (p=0.01). The ICIQ-FLUTS total score was significantly higher (p $\leq$ 0.001) in participants who experienced SUI during running, which was driven by the results from the Urinary Incontinence subscale. Although an effort was made to recruit runners who exclusively leaked urine during running, most reported leaking during other activities of daily living such as during coughing and sneezing at a minimum of a few times per year.

Table 3.1 Demographic information

	No SUI with running (n=20)		SUI with running (n=19)			Significance
	Mean / n	SD / %	Mean / n	SD / %		
Age (years)	36.2	7.9	43.9	10.6	a	0.01*
SUI with other activities (n,%)	8	40%	16	84%	b	$\chi(1) = 8.046$, p = 0.005*
BMI (kg/m ²)	22.0	2.3	24.2	5.0	a	0.184
Waist to hip ratio	0.8	0.1	0.8	0.1	a	0.550
Parous (n, %) ±	6	30%	11	58%	b	$\chi(1) = 3.083$, p = 0.079
Primipara (n, %)	3	15%	1	5%	b	$\chi(1) = 1.004$, p = 0.316
Multipara (n, %)	3	15%	10	53%	b	$\chi(1) = 6.209$, p = 0.013*
Use of forceps (n, %)	1	5%	3	16%	b	$\chi(1) = 1.232$, p = 0.267
Use of suction (n, %)	0	0%	3	16%	b	$\chi(1) = 3.421$, p = 0.064
Menopause (n, %)	1	5%	3	16%	b	$\chi(1) = 1.232$, p = 0.267
Pelvic floor muscle training (n, %)	2	10%	6	32%	b	$\chi(1) = 2.783$, p = 0.095
Signs of complete avulsion (n, %)	1	5%	0	0%	b	$\chi(1) = 0.975$, p = 0.323
Signs of partial avulsion (n, %)	3	15%	4	20%	b	$\chi(1) = 0.242$, p = 0.622
ICIQ-FLUTS total score (/48)	5.0	4.2	9.9	3.3	a	<.001*
ICIQ-FLUTS F (/16)	2.7	2.2	3.3	2.1	a	0.351
ICIQ-FLUTS V (/12)	0.7	2.0	0.8	1.3	a	0.322
ICIQ-FLUTS I (/20)	1.7	2.0	5.8	2.3	a	<.001*
ICIQ-Bowel total score (1-75)	7.9	6.3	9.3	7.5	a	0.296
ICIQ-Bowel pattern (1-21)	3.2	1.4	3.8	1.4	a	0.235
ICIQ-Bowel control (/28)	2.2	2.7	2.8	3.3	a	0.365
ICIQ-Bowel quality of life (/26)	2.5	4.6	2.7	3.6	a	0.513
ICIQ-Vaginal symptoms (/53)	2.7	3.2	4.4	6.0	a	0.461
ICIQ-Sexual Matters (/58)	6.9	9.8	3.8	7.9	a	0.478
ICIQ-Vaginal quality of life (/10)	0.7	1.3	0.7	1.1	a	0.923
IPAQ total activity (MET-minutes/week)	3294.7	2122.5	5497.0	8089.7	a	0.687
IPAQ sub total vigorous activities (MET-minutes/week)	1278.0	918.2	1708.9	3099.0	a	0.531

Values are presented as mean ± standard deviation (SD) or the frequency and percentage. Significant differences ($\alpha = \leq 0.05$) between groups are indicated by * and are in bold.

Significance represents the level for between-group differences from the Mann Whitney U test^a and the Chi Square test^b.

SUI = stress urinary incontinence; BMI = body mass index; ICIQ-FLUTS = International Consultation on Incontinence - Female Lower Urinary Tract Symptoms Long Form module; IPAQ = International Physical Activity Questionnaire; MET = metabolic equivalent of task. ± Caesarean deliveries were coded as nulliparous.

3.4.2 Dynamometry outcomes

The results for the PFM function as measured using intravaginal dynamometry are presented in **FIGURE 3.1**. Three participants had to repeat one passive elongation trial each due to PFM contraction. During MVC, compared to runners with no RI-SUI, the rate of force development was higher in those with RI-SUI ($p \leq 0.05$, $d = 0.40$). Conversely, during passive tissue elongation, the rate of force development was lower in those with RI-SUI ($p \leq 0.05$, $d = 0.80$). Active force outcomes measured during the MVC (relative peak force and endurance) tended to be higher in participants with RI-SUI ($d = 0.45$ and $d = 0.40$, respectively), while relative peak force during passive tissue elongation tended to be lower ($d = 0.49$), however these were not statistically significant. Baseline forces and SRc had small effect sizes ($d = 0.01$ and $d = 0.17$ respectively).

3.4.3 Ultrasound imaging outcomes

3.4.3.1 3D USI outcomes

PFM outcomes measured from 3D USI are presented in **FIGURE 3.2**. The CSA of the urethral wall tended to be larger among those with RI-SUI ($d = 0.50$), while the area and diameters of the levator hiatus at rest and during peak MVM also tended to be larger ($0.35 < d < 0.63$), but these trends were not significant. The change in levator hiatus area, and its associated AP and ML diameters during the MVM was not different between the groups ($0.06 < d < 0.14$).

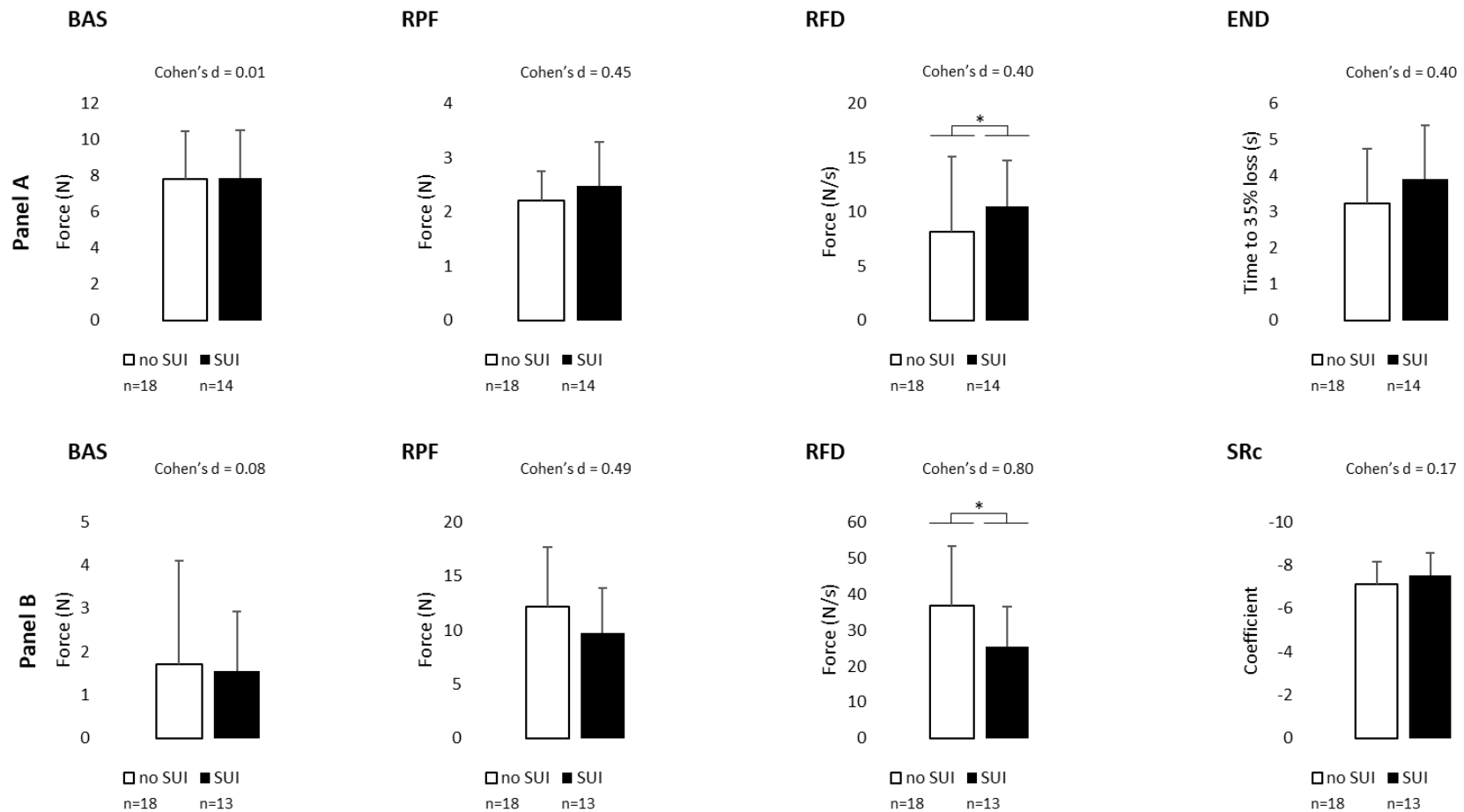


Figure 3.1 Pelvic floor muscle function as measured by intravaginal dynamometry is presented for a maximal voluntary contraction (MVC) in Panel A and during passive tissue elongation in Panel B for runners without (in white) and with (in black) running-induced stress urinary incontinence. The mean active force in Newtons (N) with the standard deviations are presented for the baseline values (BAS) and the relative peak force (RPF). Endurance (END) is presented as the time in seconds taken to lose 35% of the force after the peak force was reached during the MVC. The rate of force development (RFD) in Newtons per seconds (N/s) is presented for both MVC and the passive tissue elongation, and the stress relaxation response was measured by the stress relaxation coefficient (SRc) during the passive tissue elongation. The * indicates a significant difference ($\alpha \leq 0.05$) between groups. Cohen's d values are presented for each outcome. Missing data was due to equipment malfunction.

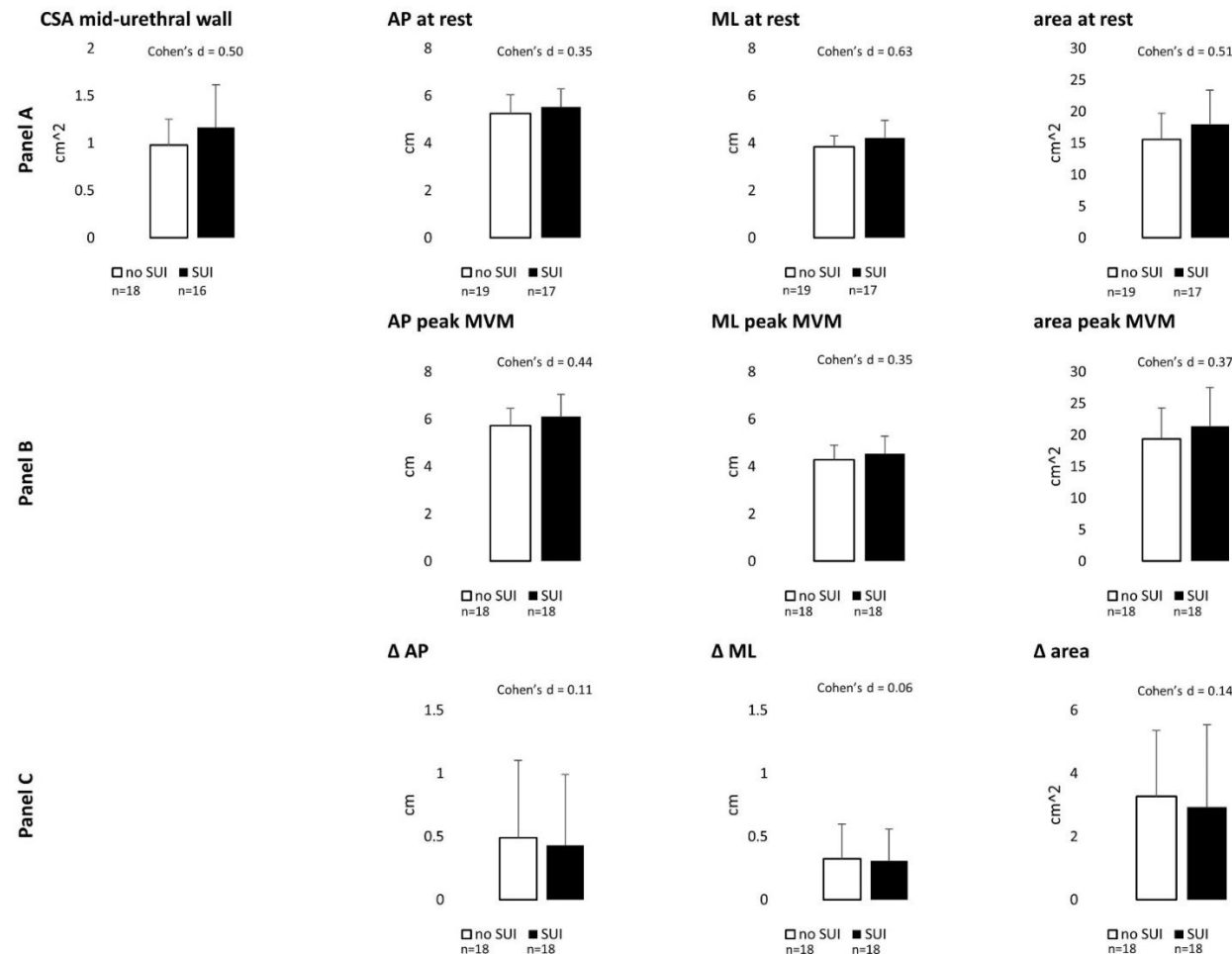


Figure 3.2 Mean pelvic floor morphology outcomes obtained from the 3D ultrasound imaging in standing are presented for runners without (in white) and with (in black) running-induced urine leakage. The standard deviations are presented for each outcome as error bars. The mean cross-sectional area (CSA) of the urethral wall in centimeters square, as well as the anteroposterior (AP) diameter, the mediolateral (ML) diameter in centimeters, and the area of the levator hiatus in centimeter square are presented both at rest (Panel A) and during peak maximal Valsalva manoeuvre (MVM) (Panel B). The difference (Δ) between the initial and end position during the MVM is presented in Panel C. The * indicates a significant difference ($\alpha \leq 0.05$) between groups. Cohen's d values are presented for each outcome. Missing data was due to poor volume quality.

3.4.3.2 2D USI outcomes

PFM outcomes measured from dynamic 2D USI are presented in **FIGURE 3.3**. During MVC, BN height increased more among those with RI-SUI than those without ($p \leq 0.05$, $d = 0.50$). No other 2D USI outcomes were significantly different between the groups, although the resting position of the BN tended to be lower among those with RI-SUI ($d = 0.50$). While not significant, the BN tended to sit more caudally at peak MVC ($d = 0.27$) and peak MVM ($d = 0.28$) among those with RI-SUI compared to their continent counterparts. A similar trend was observed for LP length during MVC. The LP length did not differ between groups at rest nor during peak MVC or MVM ($0.00 < d < 0.17$), however the runners with RI-SUI tended to generate more shortening of their levator plate during the MVC ($d = 0.29$) and less elongation of their levator plate during the MVM ($d = 0.21$) than their continent counterparts.

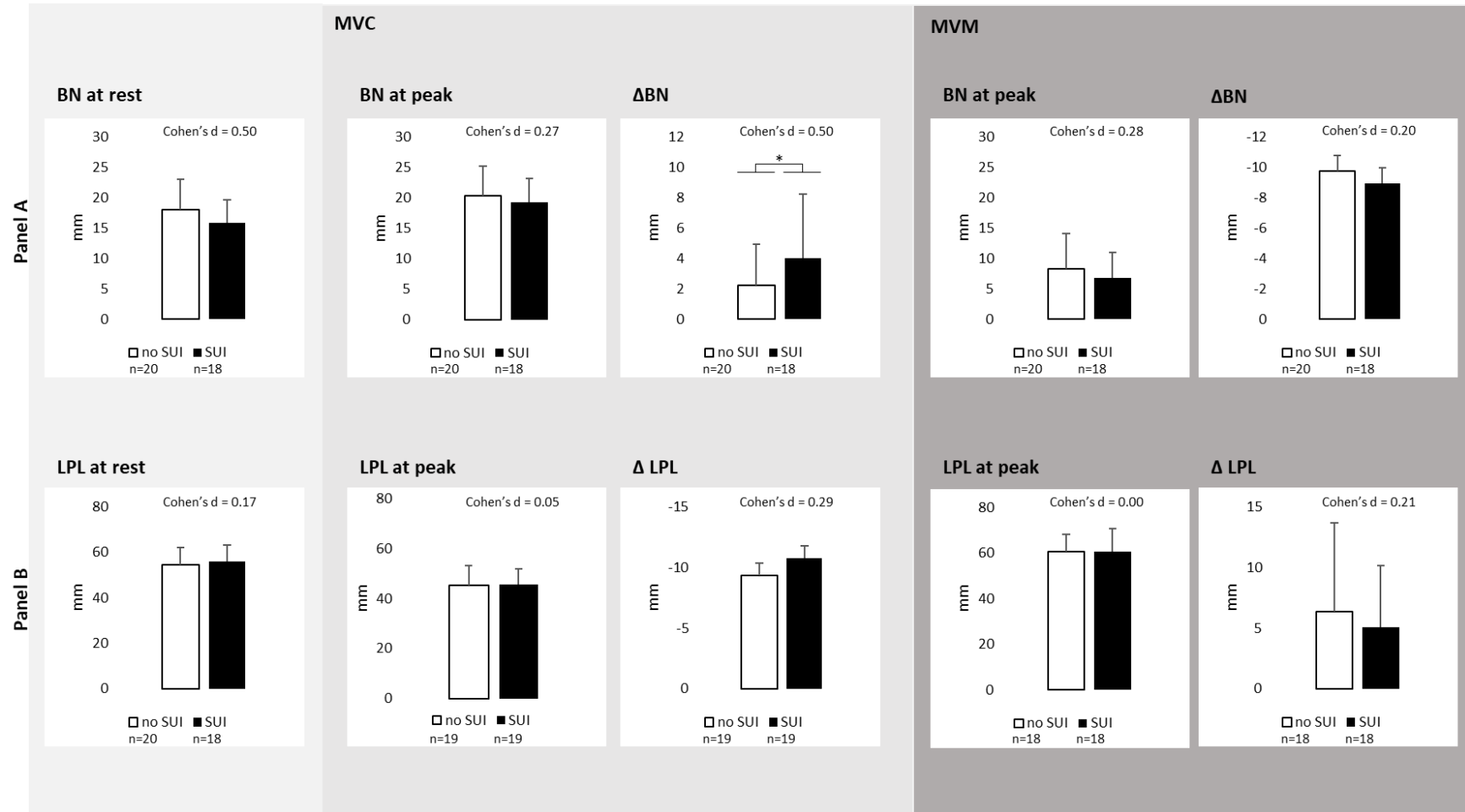


Figure 3.3 Mean pelvic floor morphology outcomes obtained from 2D ultrasound imaging in standing are presented for runners without (in white) and with (in black) running-induced leakage. The standard deviations are presented for each outcome as error bars. The bladder neck (BN) position at rest in millimeters (mm), during peak maximal voluntary contraction (MVC) and during peak maximal Valsalva manoeuvre (MVM) are presented in panel A, as well as the difference (Δ) between the initial and end position during both tasks. The levator plate length measurements for both tasks are presented in Panel B. The * indicates a significant difference ($\alpha \leq 0.05$) between groups. Cohen's d values are presented for each outcome. For simplicity, the figure for BN at rest is pulled from the average of three trials before the MVM trials started. However, the difference (Δ) between rest and peak position during the MVC are presented for that task—this decision was made to limit the number of figures. Missing data was due to poor image quality.

3.5 Discussion

To our knowledge, no published studies have reported on PFM morphology and function measured concurrently using USI and intravaginal dynamometry to uncover potential adaptations in pelvic floor support and function associated with RI-SUI. The results of this study point to adaptations including improved contractile ability of the PFMs, reflected by more rapid force development, or power, in the anteroposterior direction, greater lift of the BN during PFM MVC and greater thickness of the urethral wall, as well as less effective passive support reflected by slower passive force development, or stiffness, during elongation of the paravaginal tissues, and lower BN height at rest. Because the runners with and without RI-SUI had similar running experience and volume, these adaptations do not appear to be solely related to cumulative loading of the pelvic support structures as a result of running. Greater PFM power might reflect a compensation for the loss of tissue stiffness and urethral support observed among the runners who leak urine but not among the continent runners.

The results of this study are generalizable to experienced female runners who run a minimum of 10 km / week and who have done so for at least one year. Although our sample consisted of runners who run as a main form of physical activity, they can be reasonably extrapolated to other physically active females who run similar volumes as part of other physical activities. Our sample consisted of a balanced proportion of nulliparous and parous middle-aged (28 year to 66 years) pre-menopausal (45 of 49) runners that were mostly Caucasian (48 of 49), and as such, the results are to be interpreted within this context.

3.5.1 Intravaginal dynamometry

Results from this study provide primary evidence that runners who experience RI-SUI demonstrate better capacity to rapidly develop contractile force of their PFMs during MVC. Although other measures did not reach statistical significance, the relative peak force observed during the MVC and endurance were also higher in the SUI group and had moderate effect

sizes when compared to the runners who do not leak urine. While these differences may be the result of adaptations to counteract urine leakage, the mechanisms underlying these changes remain unknown. A systematic review investigating PFM activity during impact in continent and incontinent females suggested those with SUI demonstrate delayed PFM activity (Moser et al., 2018), however, the EMG methods used to measure PFM activation during high-impact may be invalid due to the high likelihood of crosstalk and motion artifact contamination (Falah-Hassani et al., 2021; Keshwani & McLean, 2015). Although the current findings appear contradictory, it is plausible that the delay in PFM activation is related to reduced stiffness in the PFMs among those who experience SUI during running (Maffiuletti et al., 2016). In turn, the PFMs may adapt to this delay by increasing their ability to generate force more rapidly, as was observed here. Changes in fiber type composition and motor unit discharge rate could also play a role (Maffiuletti et al., 2016), however this was not assessed in the present study. The trends towards higher relative peak force and endurance among the runners with RI-SUI differ from those by De Melo et al., who reported lower vaginal squeeze pressures and lower endurance among runners with incontinence (de Melo Silva et al., 2020). While the effect sizes were moderate in this study, these results were not statistically significant in either study. The discrepancy in results may be related to the difference in measurement tools; De Melo et al used vaginal manometry in supine to evaluate the PFM squeeze pressure and endurance whereas we used dynamometry in standing (de Melo Silva et al., 2020). We chose to measure PFM forces in standing to observe PFM function in a gravity-dependent position, which is a more accurate reflection of how the pelvic floor is loaded during running. Additionally, 6 runners with RI-SUI mentioned engaging in ongoing PFM training, while only 2 continent runners reported doing so. Although the difference was not significant between cohorts, it is possible that PFM training among runners with RI-SUI may have had a positive impact on their PFM function, including strength and power.

The rate of force development during passive elongation (i.e., stiffness) of the levator ani was lower in runners with RI-SUI compared to their continent counterparts. While it was not significant, the relative peak force at the maximal opening of 40 mm was also lower in the runners with RI-SUI and had a moderate effect size. These results suggest that strain of the PFMs and surrounding connective tissues may be a mechanism that contributes to RI-SUI. To our knowledge, this is the first study to have used intravaginal dynamometry to measure the passive properties of the PFMs in female athletes—therefore, it is not possible to compare these results to other studies. While one study that investigated the passive force values between females with and without SUI during activities of daily living using intravaginal dynamometry found no statistical group difference (Verelst & Leivseth, 2007), another found lower stiffness among those with SUI (Morin et al., 2004). Differences in aperture, speed of opening, protocols, and sample characteristics likely contributed to these different results. A standardized approach to the measurement of passive tissue properties is needed.

The MVC force outcomes obtained from the dynamometry measurements support the theory that runners with leakage, consciously or unconsciously, train their PFMs during running by contracting them to prevent leakage, inducing a training effect relative to continent runners (Leitner et al., 2017). While it is plausible that runners who leak urine compensate for lower stiffness in their PFMs and other connective tissue supports, this strategy was not effective, since this sample still leaked urine during running. For this reason, it appears that reduced stiffness of the pelvic floor connective tissues might be the predominant factor driving RI-SUI symptoms. Greater adaptations to PFM strength and power may be needed to counteract strain in the passive structures. Indeed, a recent systematic review concluded that athletes with incontinence benefit from PFM training, which decreases the frequency and the amount of leakage (Fukuda et al., 2022), yet it does not eliminate it.

3.5.2 Ultrasound imaging

The CSA of the urethral wall, measured using USI, reflects the thickness of the striated urethral sphincter and the connective tissues of the outer wall and tended to be larger among participants with RI-SUI than those without SUI, with a moderate effect size. While it is impossible to compare these results to other studies involving female athletes, two previous studies reported that women who experienced SUI during activities of daily living had smaller cross-sectional area of the urethral wall compared to continent participants (Kirschner-Hermanns et al., 1994; Kuo, 1998). We hypothesize that female athletes who leak urine may, as with their levator ani muscles, contract the striated urethral sphincter to enhance urinary continence control as a means of compensating for a loss of passive support of the pelvic structures. This hypothesis would need to be investigated through other measures, such as urodynamic assessment.

While most published research reports pelvic floor morphology as observed in a supine position, we chose to measure the area of the levator hiatus and the height of the BN in standing in order to observe its morphology in a gravity-dependent position, which is a more accurate reflection of the normal position of the pelvic structures during gait-based activities. Although moderate effect sizes suggested the levator hiatus is larger at rest among those with RI-SUI compared to continent controls, these findings did not reach significance; a larger sample size might achieve significance. Again, while 3D USI has not previously been used in this population, studies investigating SUI in the general population report similar outcomes to the ones from this study, suggesting that loss of passive support plays a role in the pathophysiology of SUI (Falah-Hassani et al., 2021).

Dynamic 2D USI was also captured in standing to evaluate the effect of MVC and MVM on changes in pelvic morphology in a functional position. Two findings are of particular note. First, the BN height at rest in standing was lower among those with RI-SUI compared to the

control group, suggesting that, consistent with the dynamometry findings, the bladder and urethral support structures may be strained in runners who experience SUI. Second, during the MVC, the runners with RI-SUI elevated their BN more than continent runners. Again, consistent with the dynamometry measures, this may reflect a compensatory mechanism to provide more support to the urethra and may assist with externally compressing it to prevent leakage during running. Although it was not significant, a similar trend was observed in the LP length—albeit with a small effect size.

While it is not yet understood why and how changes in the pelvic floor morphology and function occur in runners with leakage as opposed to continent runners with similar running experience, running volume, and parity, the findings of this study support the following two hypotheses: (1) that females with RI-SUI experience greater pelvic floor loading during running activities (due to higher intra-abdominal pressure or gravitational loading) which results in strain of the pelvic support structures, and/or (2) that females with RI-SUI have less effective pelvic organ support for reasons outside of cumulative loading induced by running. Further research is needed to test these hypotheses.

3.5.3 Limitations

Limitations of this study include the inherent recruitment bias of cross-sectional designs—the female runners who attended the laboratory assessment were likely interested in their pelvic health *a priori*. In addition, because 23% of participants with urinary symptoms will stop engaging in running as a result of their condition (Dakic et al., 2021)—our sample may be biased towards those with less severe symptoms because those who participated had not stopped running due to UI. A group of female runners who are contemplating or have recently stopped running due to UI should be recruited to evaluate the presence and the extent of any differences in the PFM function and morphology compared to those who participated in the current study.

Vaginal birth is acknowledged as a risk factor for UI and it is likely to influence the structure and function of the PFMs. Despite attempts to match the groups on parity during the recruitment process, there were more multiparous female runners among those with RI-SUI compared to those without. Despite this difference, there were equal numbers of participants in each group (n=4) who presented with levator avulsion, yet other parity-related changes to the pelvic floor may have influence the outcomes of this study. Because the samples were not matched in terms of parity, we ran a post-hoc analysis looking at nulliparous runners only to determine whether parity may have influenced the findings. Among nulliparous runners, the statistical outcomes followed the same trends as observed in the overall sample. For example, on dynamometry, the nulliparous runners with RI-SUI (n=4) had higher rate of force development during contraction (12.1 vs 8.7 N/s), yet lower rate of force development during passive elongation (34.8 vs 40.7 N/s) than nulliparous runners without RI-SUI (n=12). On USI, the nulliparous runners with RI-SUI (n=8) had a BN position that was significantly lower (15.0 vs 19.7 mm) than what was observed in nulliparous runners without RI-SUI (n=14). Further research with a larger participant pool is essential to establish the interaction between RI-SUI and parity.

The cross-sectional nature of this study does not allow the results to contribute to the debate regarding the impact of exercise on pelvic floor function, where some advocate that high impact exercise is harmful (Karmakar & Dwyer, 2018), and others report that the evidence for harm is scant (Bo & Nygaard, 2020), and that women should not be discouraged to participate in high intensity training (Kruger, 2018).

Lastly, it is important to note that changes in the levator hiatus area measured during the MVM in standing might have been compromised by co-contraction of the PFMs. While both running groups were provided with extensive cueing and feedback using USI on how to perform a proper MVM with concurrent pelvic floor relaxation, consistent with several previous reports

(Baessler et al., 2017; Örnö & Dietz, 2007; Thibault-Gagnon et al., 2014; Thyer et al., 2008), a co-contraction of the pelvic floor was observed in 9 out of 20 continent runners (45%) and in 6 of 19 incontinent runners (32%). While we chose to include the MVM task to measure the extent to which the connective tissues of the pelvic floor experience strain during running, levator ani co-contraction might have limited the caudal movement of the BN and the lengthening of the LP observed in the 2D sagittal imaging, as well as the increase in levator hiatus area, AP diameter and ML diameter during the 3D imaging. These findings should therefore be interpreted with caution.

3.6 Conclusion

The novel methods used in this study add to our understanding of the pathophysiology of RI-SUI. The significant changes and moderate effect sizes found in the active and passive properties of the pelvic tissues suggest that runners with RI-SUI demonstrate improved PFM function (capacity to lift cranially, and power of vaginal closure force, thicker urethral wall) and impaired pelvic organ support (BN height in standing and stiffness in the levator ani muscle). While we cannot be certain that the improvement in PFM contractile abilities is compensatory, we hypothesize that this is the case. Future research should aim to investigate the impact of an acute bout of running on the active and passive properties of the pelvic floor, should quantify the extent of pelvic floor loading experienced by the pelvic floor during running, and should apply a longitudinal study design to appreciate the time course and progression of changes observed in the contractile and stiffness characteristics of the pelvic floor.

3.7 Supplemental material

3.7.1 Intravaginal dynamometry outcomes

3.7.1.1 Maximal voluntary contraction in standing

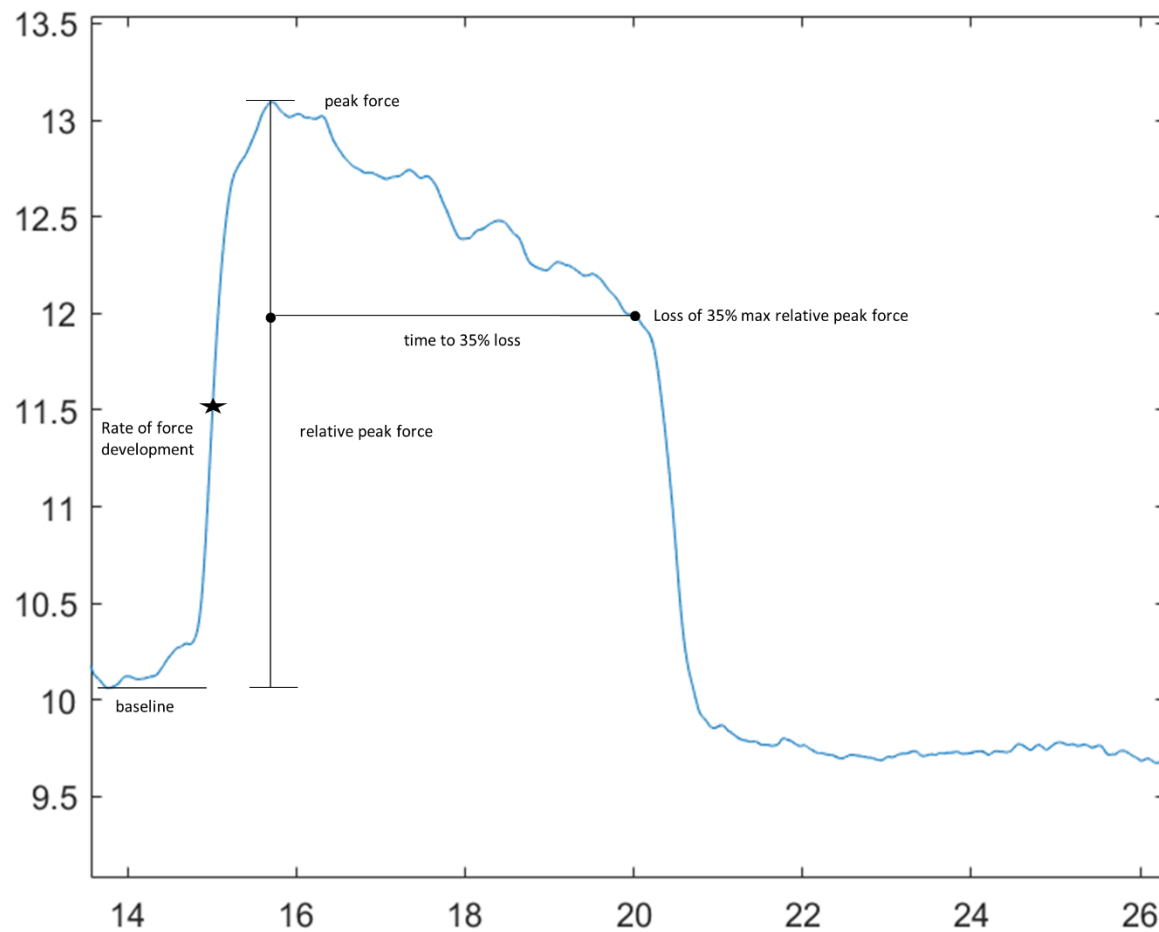


Figure 3.4 Sample active force data recorded during a maximal voluntary pelvic floor muscle contraction performed with the dynamometer anteroposterior diameter set at 35 mm.

3.7.1.2 Passive tissue elongation in supine

To provide additional clarity, we have included a sample of a stress-strain curve (Figure S2) recorded during passive tissue elongation (ranging from 15 to 40 mm) from a parous runner with a longer levator plate at rest when standing (62.6 mm) and from a nulliparous runner with a shorter levator plate at rest when standing (47.0mm) (Figure S3). This curve demonstrates that adequate tissue contact is maintained throughout the protocol. You will note that there is closure force on the dynamometer arms even before they are opened (i.e. at a diameter of 15mm) and that the force increases monotonically throughout the opening phase to the full 40mm opening, followed by a tissue stress relaxation response.

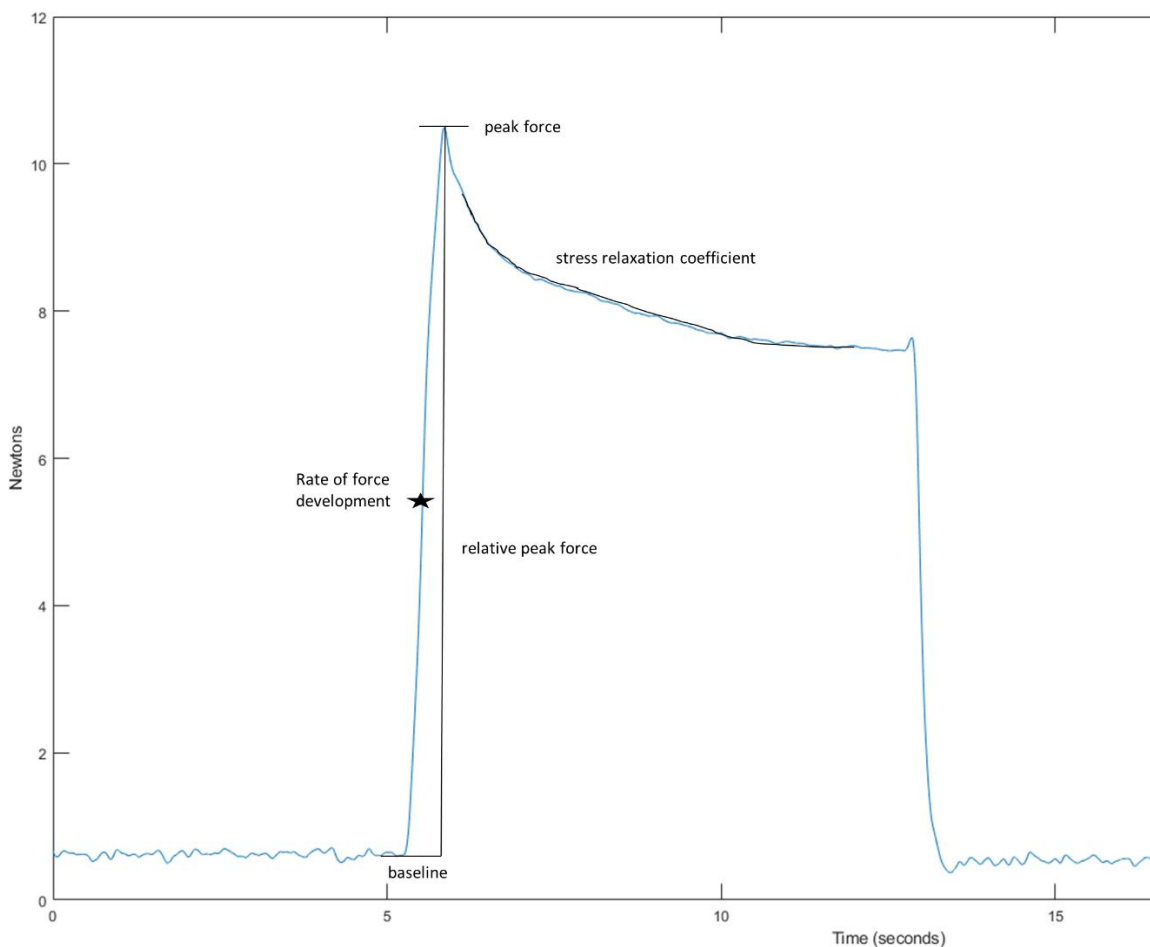


Figure 3.5 Sample raw force data recorded during passive tissue elongation of a runner with a longer levator plate (62.6mm) while the dynamometer arms opened from 15mm to a maximum anteroposterior diameter of 40mm at a rate of 50mm/s. The tissues were held in place for 7 seconds while the stress relaxation occurred before the arms returned to their initial position.

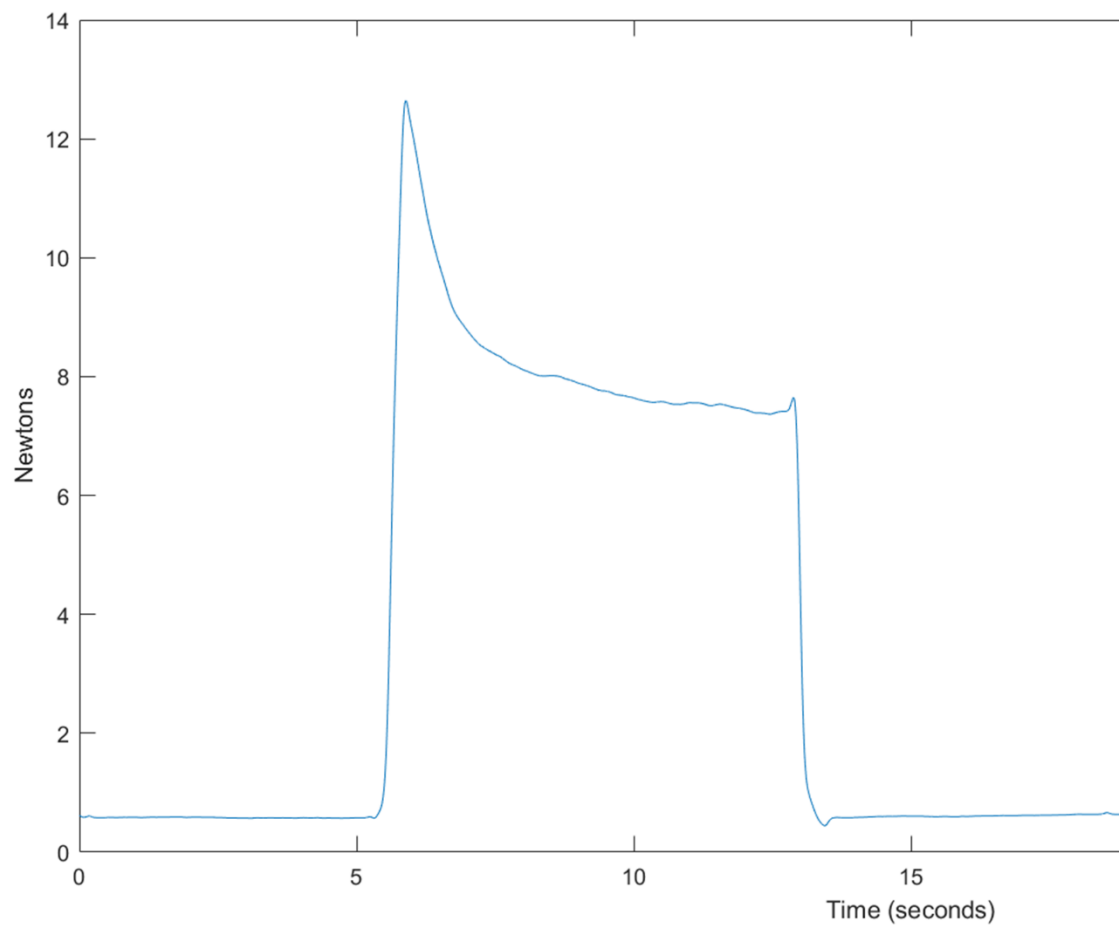


Figure 3.6 Sample raw force data recorded during passive tissue elongation of a runner with a shorter levator plate (47.0mm) while the dynamometer arms opened from 15mm to a maximum anteroposterior diameter of 40mm at a rate of 50mm/s. The tissues were held in place for 7 seconds while the stress relaxation occurred before the arms returned to their initial position.

3.7.2 Transperineal ultrasound imaging in standing

3.7.2.1 3D hiatus

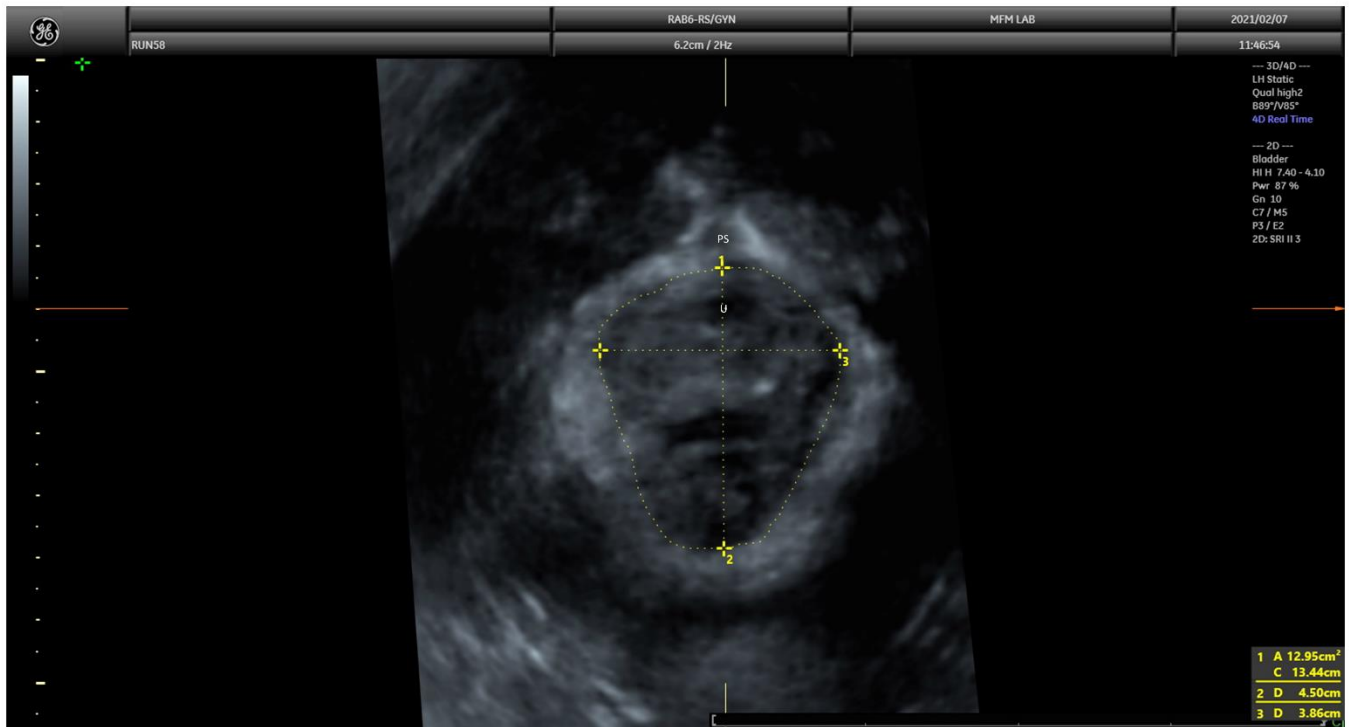


Figure 3.7 Levator hiatus rendered in 4D View®. The yellow line denotes the measure of the area (1) as well as its related anteroposterior (2) and mediolateral diameters (3). The pubic symphysis (PS) and urethra (U) are indicated in white.

3.7.2.2 2D sagittal imaging

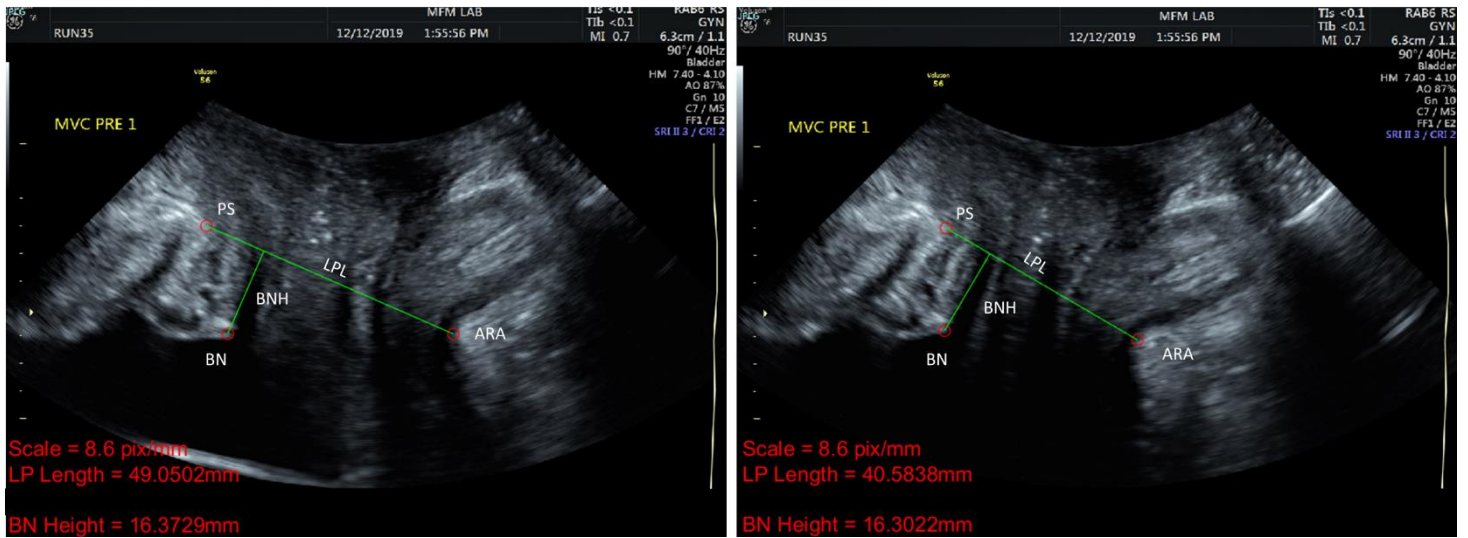


Figure 3.8 Sagittal view of the pelvic complex. The levator plate length (LPL) was measured from the pubic symphysis (PS) to the anorectal angle (ARA) and the bladder neck height (BNH) was calculated from the anterior aspect of bladder neck (BN) perpendicularly to the LPL. The left panel illustrates the pelvic complex at rest and the right panel, during peak maximal voluntary contraction.

3.7.2.3 Urethra



Figure 3.9 The cross-sectional area (CSA) of the urethral wall at the mid-urethra rendered in 4D View. It is calculated by subtracting the area bordered by the hypoechoic longitudinal urethra wall (2) from the external border of the hyperechoic urethral wall (1).

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Chapter 4 The Acute Effects of Running on Pelvic Floor Morphology and Function in Runners With and Without Running-Induced Stress Urinary Incontinence

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A copy of this publication is attached in Appendix R.

Authors' Contributions statement:

ME Bérubé: Project development, Data collection, Manuscript writing, Revision process

L McLean: Project development, Manuscript writing, Revision process

4.1 Abstract

Introduction:

The aim of this study was to examine the impact of a single running session on pelvic floor morphology and function in female runners, and to compare those with and without running-induced stress urinary incontinence (RI-SUI).

Methods:

This cross-sectional, observational study involved two groups: female runners who regularly experienced RI-SUI (n=19) and runners who did not (n=20). Pelvic floor muscle (PFM) properties were assessed using intravaginal dynamometry during maximal voluntary contractions (MVC) and during passive tissue elongation. The morphology of the pelvic floor was assessed at rest, during MVC and during maximal Valsalva maneuver (MVM) using 2D and 3D transperineal ultrasound imaging before and after a running protocol. Mixed-effects ANOVA models were used to compare all outcomes between groups and within-groups including the interaction between group and time. Effect sizes were calculated.

Results:

No changes in PFM function assessed using intravaginal dynamometry were observed in either group after the run. Significant and large within-group differences were observed on ultrasound imaging. Specifically, the area and anteroposterior diameter of the levator hiatus were larger after the run, the bladder neck height was lower after the run, and the levator plate length was longer after the run ($p \leq 0.05$). At the peak MVM and MVC, the bladder neck height was lower after the run compared to before the run ($p \leq 0.05$). No between-group differences were observed for any outcomes.

Conclusion:

Running appears to cause transient strain of the passive tissues of the female pelvic floor in runners both with and without RI-SUI, while no concurrent changes are observed in PFM contractile function.

4.2 Introduction

Stress urinary incontinence (SUI), the complaint of involuntary urine loss (Dourmouchtsis et al., 2023) that occurs when the bladder pressure exceeds the urethral capacity to remain closed, is the most commonly reported pelvic floor dysfunction during high-impact activities (Teixeira et al., 2018) and can limit females from participating in an active lifestyle (Dakic et al., 2021; Nygaard et al., 2005). There is ongoing debate in the literature regarding the impact of exercise on pelvic floor function. While some advocate that high impact exercise is harmful and may induce strain on the structures that provide support (Karmakar & Dwyer, 2018), the evidence for harm is scant and some researchers encourage females to participate in high intensity training, noting that risk is low and that exercise may improve pelvic floor support and strength (Kruger, 2018). Both hypotheses are supported by a review (Teixeira et al., 2018) which reported that females who engaged in physical activity had a 177% higher risk of reporting urinary incontinence than sedentary females, yet, concurrently noted that exercise, when done at mild to moderate intensity, was protective of the pelvic floor, decreasing the odds and the risk of experiencing urinary incontinence (Kim et al., 2022).

As with SUI in the overall population, multiple factors such as neuromuscular damage and structural damage to the urethra and the levator ani muscles as well as their associated connective tissues (Falah-Hassani et al., 2021; Gan & Smith, 2023) are likely implicated in SUI experienced during athletic activities. Yet repetitive loading of the pelvic floor may, over a bout of exercise, lead to muscle fatigue and/or tissue strain which additionally contributes to urine leakage during repetitive high impact activities such as running (Gan & Smith, 2023). Indeed, some researchers have reported that SUI during training occurs mainly during the middle or at the end of training sessions (Carvalhais et al., 2018).

To our knowledge, no studies have investigated the acute, transient impact of running on pelvic organ support and pelvic floor muscle (PFM) function, nor compared these effects between females who experience running-induced stress urinary incontinence (RI-SUI) and those who do not. Such robust biomechanical data are needed to fully understand the acute effects of running on pelvic floor morphology and function. Considering the absence of previous research in this area, the goal of this study was to provide critical insight into the impact of running exposure on pelvic floor morphology and function in female runners. We hypothesized that all runners would demonstrate evidence of levator ani muscle fatigue and a reduction in connective tissue support after the run, and that these changes would be more marked among runners with RI-SUI. The study was developed to generate new knowledge that would contribute to the development of targeted, evidence-based pelvic floor physiotherapy interventions for exercise induced urine leakage, particularly during running.

4.3 Methods

4.3.1 Design

This cross-sectional, observational study received prior approval from the local institutional research ethics board. Data were collected between June 2019 to March 2021, with a pause between March 2020 and January 2021 due to laboratory closures caused by the COVID-19 pandemic.

4.3.2 Participants

Female runners assigned female at birth, over 18 years of age and with no known risk factors related to physical activity (as determined by the administration of the Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) (Shephard, 1988) were recruited from the local community through local running groups and physiotherapy clinics. To meet the eligibility

criteria, which aimed to ensure that runners had sufficient, regular and prolonged exposure to high impact loading of the pelvic floor through running, volunteers were required to run at least 5 km in under 50 minutes, twice a week, and to have maintained an average running distance over 10 km per week for a minimum of one year. Runners were recruited into two groups, intended to be matched by age and parity: (1) runners who frequently experienced SUI (one or more episodes per week) while running and (2) those who did not. Runners with SUI during running who reported using mitigation strategies (voiding their bladder before/during the run, running slower, avoiding hills, etc.) to avoid leakage were included if they leaked more than once per week when not using these strategies and still leaked a minimum one leakage episode while running per month while using these strategies. Participants were not excluded if they experienced occasional instances of urinary urgency during running without any associated leakage. Runners were excluded if they presented with a history of urogenital surgery or neurological disorders, if they reported symptoms of low energy deficiency as measured by the Low Energy Availability in Females Questionnaire (LEAF-Q) (Melin et al., 2014), if they were pregnant or if they had delivered a baby within the previous year, if they had a pelvic organ prolapse that was caudal to the hymen on a maximal Valsalva maneuver (MVM) in a standing position, or if they experienced pelvic pain to the extent that they were not able to undergo an intravaginal examination using a speculum. They were also excluded if they reported leakage associated with urgency during running. After providing written informed consent, all eligible participants provided demographic information including age, parity, obstetrical history (i.e. vaginal vs caesarean section, use of forceps or vacuum) and menopausal status, and were asked to complete the International Consultation on Incontinence - Female Lower Urinary Tract Symptoms Long Form module (ICIQ-FLUTS) (Abrams et al., 2006), the Anal Incontinence Symptoms and Quality of Life module (ICIQ-B) (Cotterill et al., 2011), the Vaginal Symptoms module (ICIQ-VS) (Price et al., 2006), and the International Physical Activity Questionnaire (IPAQ) (Hagströmer et al., 2006) .

4.3.3 Laboratory assessment

The laboratory assessment was performed by a registered physiotherapist trained in pelvic health and with over 5 years of experience in this practice area, who also received over 50 hours of training on intravaginal dynamometry and ultrasound imaging, and had over 2 years of experience using these instruments.

The morphology of the PFMs was assessed using 2D and 3D B-mode transperineal ultrasound imaging (USI) via a GE Voluson S6 system (General Electric, Toronto, Canada) with a standardized bladder volume between 100 and 200mL. In a standardized standing position, static (3D) and dynamic (4D) volumes were acquired at rest and while the participant performed an MVM. 2D ultrasound videos were then recorded during MVM and maximal voluntary contraction (MVC) efforts of their PFMs. Next, still in standing, participants were instrumented with an intravaginal dynamometer and performed an MVC against arms opened to an anteroposterior diameter of 35 mm. In supine, passive forces were then recorded while the diameter of the dynamometer arms moved from 15 mm to 40 mm at a constant speed (50 mm/s). The elongation was held for 7 seconds before the arms returned to their initial position. Three repetitions of each task were performed.

Measures of PFM morphology in 3D included the area of the levator hiatus and its related anteroposterior (AP) and mediolateral (ML) diameters both at rest and during peak MVM, as well as their change from the start to the peak position during the MVM. Signs of complete and partial levator avulsion were evaluated using the 3D rest volume in standing and the techniques described by Dietz et al (Dietz et al., 2008; Dietz et al., 2011). The measures acquired in 2D included bladder neck (BN) height and levator plate (LP) length and their change from the start to the peak position during each task (MVC and MVM) (Dietz, 2004; McLean et

al., 2016). These measures have been found to have adequate reliability for use in research (Brækken et al., 2008; Majida et al., 2009, 2010). Measures of PFM function acquired through dynamometry included baseline force, relative peak force, rate of force development, and static endurance measured as the time from the initial force achieved during the MVC until force decreased by 35% (Bérubé et al., 2018; Czyrnyj et al., 2021). Passive tissue forces measured during tissue elongation included baseline force, relative peak resistance, rate of force development (stiffness), and the stress relaxation coefficient (SRc). The validity and reliability of these measures and all details of the standardized procedures can be found in previous publications (Bérubé et al., 2018; Czyrnyj et al., 2021).

With a pre-weighed incontinence pad in situ and a Fitbit Charge 2 worn on the left wrist, the participant began a standardized running protocol on a treadmill (NordicTrack Commercial 2450). Participants increased the belt speed on the treadmill at a self-selected rate to move from walking to a slow jog at a speed of 7 km/h. At this speed, they ran for 2 minutes, then incremented the belt speed to 10 km/h for 2 minutes, and finally to 15 km/h for 2 minutes (Leitner et al., 2017). The participants were permitted to reduce the belt speed from 15 km/h if they did not feel safe or if they did not have the capacity to run at that speed. The participants were then asked to choose a self-selected speed at an intensity which they deemed to be hard (level 15-16 on the Borg Scale), and to run at that speed for 30 minutes. After the 30-minute steady-state run, the participants ran for 30 seconds at the 10 km/h then at the 7 km/h. Participants were asked to report any instances of perceived leakage of urine while they ran. The ultrasound imaging and intravaginal dynamometry protocols were repeated as quickly as possible after the running protocol, with data collection completed within 15 minutes of the end of the run. The pad weight was recorded.

4.3.4 Statistics

Using pilot data from the area of the levator hiatus at rest in standing recorded using transperineal USI before and after a 30-minute running protocol from 8 continent runners (mean before 15.99 cm², SD 2.32 cm²; mean after 17.63 cm², SD 2.54 cm²), an *a priori* two-tailed power calculation using G*Power (version 3.0.10; $\alpha=0.05$; $\beta=0.80$; effect size d_z 0.67) estimated that a minimum of 20 continent runners would be necessary to detect within-group changes induced by the running protocol.

All demographic variables and outcomes were tested for normality using the Shapiro-Wilk test. Mixed-effects ANOVA models were used to compare all outcomes between groups (with or without RI-SUI) and within-groups (before and after the run) including the interaction between group and time. Residual plots were examined to ensure proper model fit, and effect sizes (Cohen's d) were calculated using partial eta squared; $0.2 \leq d < 0.5$ were considered small, $0.5 \leq d < 0.8$ were considered moderate, and $d \geq 0.8$ were considered large (Lee, 2016). Based on the observation that not all participants in the group with RI-SUI leaked urine during the protocol, secondary post-hoc exploratory analyses were performed using mixed-effects ANOVAs to evaluate effect sizes between runners with RI-SUI who leaked urine during the protocol vs runners with RI-SUI who did not leak during the protocol, and changes induced by the run within each group. Because of the exploratory nature of this research, the α level ($\alpha=0.05$) was not adjusted to account for multiple comparisons.

4.4 Results

4.4.1 Sample Demographic Information

The recruitment flow diagram is presented in **FIGURE 4.1**.

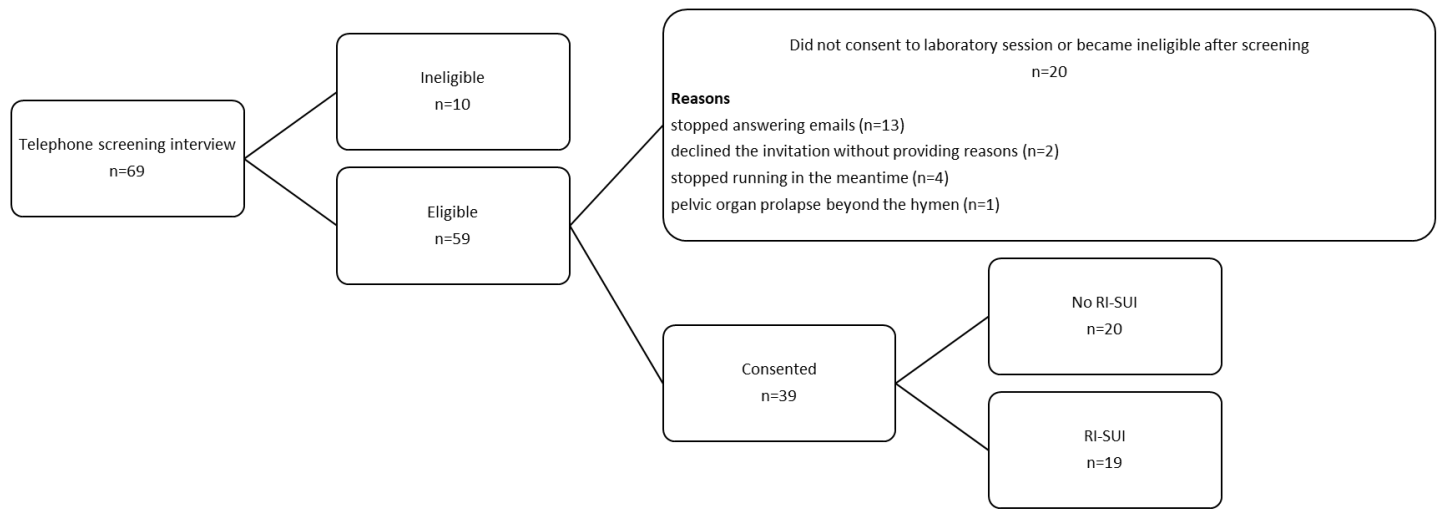


Figure 4.1 Flow diagram of the recruitment of the female runners with and without running-induced stress urinary incontinence (RI-SUI)

Twenty participants reported being continent during running, reporting fewer than three lifetime episodes of urine leakage, and nineteen runners reported experiencing frequent SUI during running. The groups were similar for most demographic outcomes (**TABLE 4.1**), however, the female runners without RI-SUI were slightly younger ($p=0.01$) and ran slightly faster ($p=0.039$) than the runners who reported RI-SUI, and although there was no difference in parity between the groups, there was a higher proportion of multiparous runners in the RI-SUI group ($p=0.013$). The ICIQ-FLUTS UI subscale score was significantly higher ($p\leq 0.001$) in runners with RI-SUI. The ICIQ-FLUTS scores indicated that 3 participants (1 without and 2 with RI-SUI) reported overactive bladder symptoms but none of them reported leakage associated with it during running. Although the runners with RI-SUI had greater pad weight gain after the running protocol than their continent counterparts (30.4g versus 8g), this was not statistically different between the groups. Seven out of the nineteen runners with RI-SUI did not report being aware of any leakage during the running protocol and had a pad weight gain of less than 8g over the course of the run. One continent participant had to discontinue the testing protocol after the

running protocol as performing the MVM during the USI assessment caused a vasovagal response.

Table 4.1 Demographic information

	No SUI with running (n=20)		SUI with running (n=19)		Significance
	Mean / n	SD / %	Mean / n	SD / %	
Age (years)	36.2	7.9	43.9	10.6	a 0.01
SUI with other activities (n, %)	8	40%	16	84%	b $\chi(1) = 8.046, p = 0.005$
BMI (kg/m ²)	22.0	2.3	24.2	5.0	a 0.184
Waist to hip ratio	0.8	0.1	0.8	0.1	a 0.55
Parous	6	30%	11	58%	b $\chi(1) = 3.083, p = 0.079$
Primipara (n, %)	3	15%	1	5%	b $\chi(1) = 1.004, p = 0.316$
Multipara (n, %)	3	15%	10	53%	b $\chi(1) = 6.209, p = 0.013^*$
Use of forceps (n, %)	1	5%	3	16%	b $\chi(1) = 1.232, p = 0.267$
Use of suction (n, %)	0	0%	3	16%	b $\chi(1) = 3.421, p = 0.064$
Signs of complete avulsion (n, %)	1	5%	0	0%	b $\chi(1) = 0.975, p = 0.323$
Signs of partial avulsion (n, %)	3	15%	4	20%	b $\chi(1) = 0.242, p = 0.622$
Menopause (n, %)	1	5%	3	16%	b $\chi(1) = 1.232, p = 0.267$
Pelvic floor muscle training (n, %)	2	10%	6	32%	b $\chi(1) = 2.783, p = 0.095$
ICIQ-FLUTS total score (/48)	5.0	4.2	9.9	3.3	a <.001
ICIQ-FLUTS F (/16)	2.7	2.2	3.3	2.1	a 0.351
ICIQ-FLUTS V (/12)	0.7	2.0	0.8	1.3	a 0.322
ICIQ-FLUTS I (/20)	1.7	2.0	5.8	2.3	a <.001
ICIQ-Bowel total score (1-75)	7.9	6.3	9.3	7.5	a 0.296
ICIQ-Bowel pattern (1-21)	3.2	1.4	3.8	1.4	a 0.235
ICIQ-Bowel control (/28)	2.2	2.7	2.8	3.3	a 0.365
ICIQ-Bowel quality of life (/26)	2.5	4.6	2.7	3.6	a 0.513
ICIQ-Vaginal symptoms (/53)	2.7	3.2	4.4	6.0	a 0.461
ICIQ-Sexual Matters (/58)	6.9	9.8	3.8	7.9	a 0.478
ICIQ-Vaginal quality of life (/10)	0.7	1.3	0.7	1.1	a 0.923
IPAQ total activity (MET-minutes/week)	3294.7	2122.5	5497.0	8089.7	a 0.687
IPAQ sub total vigorous activities (MET-minutes/week)	1278.0	918.2	1708.9	3099.0	a 0.531
Self-selected running speed (km/h)	10.8	1.2	9.7	1.8	c 0.039
Number of steps during running protocol	6586.8	424.7	6381.2	305.1	c 0.095
Pad test (g) **	8.0	5.6	30.4	41.7	a 0.127
Weekly running distance (km)	35.2	21.2	39.5	27.7	a 0.835
Running experience (years)	15.1	9.2	15.9	12.0	a 0.792

Values are presented as mean $\pm$ standard deviation (SD) or the frequency and percentage. Significant differences ($\alpha = \leq 0.05$) between groups are indicated in bold.

Significance represents the level for between-group differences from the Mann Whitney U test^a, the Chi-Square^b, or the two-sample t-test^c

SUI = stress urinary incontinence; BMI = body mass index; ICIQ-FLUTS = International Consultation on Incontinence - Female Lower Urinary Tract Symptoms Long Form module; IPAQ = International Physical Activity Questionnaire; MET = metabolic equivalent of task; km/h = kilometers per hour; g = grams

**one pad test was over 150g and our scale had an upper range of 150 g, therefore it was set to 150g.

4.4.2 Ultrasound imaging outcomes

The morphologic features of the levator hiatus at rest and during MVM are presented in **TABLE**

4.2. Significant and large main effects were found when comparing measures after the run to those measured before the run. At rest, the area ($p=0.002$; $d=1.19$) and AP diameter ($p=0.021$; $d=0.84$) of the levator hiatus were larger after the run for both groups but no change in levator hiatus morphology was observed during peak MVM when performed after the run compared to before the run. At rest, in both groups, the BN height was more caudal within the pelvis ($p<0.001$; $d=2.09$) and the LP length was significantly longer ($p<0.001$; $d=1.34$) after the run than before the run. At peak MVC and peak MVM the BN was also more caudal after the run ($p<0.002$; $d=1.20$ and $p<0.001$; $d=1.41$ respectively) compared to before the run in both groups.

The transient changes in morphological outcomes induced by MVC and MVM are presented in **TABLE 4.3** There was more shortening of the LP during the MVC ($p=0.034$; $d=0.76$) and less lengthening of the LP during the MVM ($p=0.004$; $d=1.08$) after the run compared to before the run in both groups. There was also less caudal displacement of the BN during the MVM in both groups ($p=0.041$; $d=0.73$) after the run. No significant differences were observed between groups (RI-SUI vs control) and no interactions between group and time (before vs after the run) were observed for any morphologic features measured from USI. Missing data (indicated in TABLES 4.2 and 4.3) was due to poor image/video quality that prevented the researcher from identifying landmarks (pubic symphysis, anorectal angle, anterior bladder neck) as indicated in the Tables.

Table 4.2 Comparison of intravaginal dynamometry and ultrasound imaging outcomes before and after an acute bout of running between runners with and without running-induced stress urinary incontinence.

	Before the run						After the run						Between-group		Within-group		Interaction	
	No RI-SUI			RI-SUI			No RI-SUI			RI-SUI								
	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD	p-value	Cohen's d	p-value	Cohen's d	p-value	Cohen's d
Dynamometry outcomes during MVC																		
Baseline (N)	7.90	17	2.68	7.62	12	2.79	7.28	17	2.59	7.27	12	2.16	0.875	0.06	0.172	0.54	0.702	0.14
Relative peak force (N)	3.23	17	1.56	4.21	12	1.29	3.73	17	1.89	4.16	12	1.36	0.232	0.47	0.158	0.56	0.096	0.66
Rate of force development (N/s)	8.20	17	7.09	11.21	12	3.89	8.86	17	7.88	10.29	12	4.84	0.357	0.36	0.792	0.11	0.125	0.61
Endurance (seconds)	2.23	16	0.55	2.58	12	0.82	2.12	16	1.19	2.33	12	0.70	0.336	0.39	0.288	0.42	0.670	0.17
Dynamometry outcomes during passive elongation																		
Baseline (N)	1.21	16	0.74	1.55	13	1.39	1.27	16	0.82	1.45	13	1.38	0.527	0.25	0.773	0.11	0.144	0.58
Relative peak force (N)	12.73	16	5.60	9.72	13	4.19	12.02	16	7.01	9.48	13	3.38	0.169	0.54	0.229	0.47	0.551	0.23
Stiffness (N/s)	34.25	16	10.96	25.50	13	11.09	31.58	16	11.60	25.14	13	8.60	0.056	0.77	0.228	0.47	0.355	0.36
Stress relaxation coefficient	-7.20	16	2.26	-7.54	13	2.59	-7.12	16	2.41	-6.87	13	2.30	0.947	0.00	0.548	0.24	0.638	0.18
3D US measurements at rest																		
Area (cm2)	15.65	18	4.29	18.00	17	5.35	16.37	18	4.88	18.84	17	5.16	0.153	0.51	0.002	1.19	0.792	0.09
AP diameter (cm)	5.23	18	0.80	5.52	17	0.77	5.36	18	0.86	5.68	17	0.74	0.257	0.40	0.021	0.84	0.727	0.13
ML diameter (cm)	3.86	18	0.46	4.23	17	0.73	3.86	18	0.45	4.21	17	0.64	0.068	0.66	0.870	0.06	0.883	0.06
3D US measurements on MVM																		
Area (cm2)	19.52	18	4.97	21.74	18	5.89	19.73	18	4.65	21.94	18	6.16	0.239	0.43	0.608	0.19	0.994	0.00
AP diameter (cm)	5.71	18	0.74	6.08	18	0.76	5.75	18	0.76	6.16	18	0.68	0.109	0.59	0.559	0.21	0.831	0.06
ML diameter (cm)	4.31	18	0.63	4.57	18	0.78	4.31	18	0.53	4.51	18	0.75	0.327	0.36	0.521	0.23	0.555	0.21
2D US measurements at rest																		
BN height (mm)	17.98	19	5.13	16.22	17	3.57	14.66	19	4.54	13.92	17	4.19	0.379	0.31	<0.001	2.09	0.276	0.38
LP length (mm)	54.88	19	7.48	55.81	18	7.31	57.94	19	9.40	60.01	18	8.10	0.554	0.20	<0.001	1.34	0.539	0.21
2D US measurements on MVC																		
BN height (mm)	20.83	18	4.88	19.57	17	3.91	18.45	18	5.01	18.65	17	4.27	0.721	0.13	0.002	1.20	0.135	0.53
LP length (mm)	45.37	18	8.05	45.52	18	6.23	45.60	18	8.75	45.02	18	5.91	0.929	0.00	0.768	0.11	0.443	0.26
2D US measurements on MVM																		
BN height (mm)	8.26	19	6.04	7.32	17	3.83	6.26	19	5.61	5.46	17	4.20	0.594	0.18	<0.001	1.41	0.877	0.06
LP length (mm)	60.86	17	7.48	60.85	18	9.92	62.96	17	8.60	62.86	18	9.27	0.985	0.00	0.070	0.65	0.963	0.00

RI-SUI: running-induced stress urinary incontinence; MVC: maximal voluntary contraction; MVM: maximal Valsalva maneuver; 2D: 2 dimensional; 3D: 3 dimensional; BN: bladder neck; LP: levator plate; US: ultrasound; AP: anteroposterior; ML: mediolateral; N: Newtons; N/s: Newtons per second; mm: millimeters; cm: centimeters; SD: standard deviation. Significant differences ($\alpha \leq 0.05$) are indicated in bold.

Table 4.3 Assessment of the change in position of the bladder neck and levator plate on ultrasound imaging between runners with and without running-induced stress urinary incontinence

	Before the run						After the run						Between-group		Within-group		Interaction	
	No RI-SUI			RI-SUI			No RI-SUI			RI-SUI								
	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD	p-value	Cohen's d	p-value	Cohen's d	p-value	Cohen's d
3D US change on MVM																		
Area (cm2)	3.23	18	2.16	2.92	18	2.20	3.01	18	2.01	2.09	18	2.34	0.371	0.33	0.127	0.57	0.379	0.32
AP diameter (cm)	0.46	18	0.62	0.42	18	0.54	0.35	18	0.55	0.27	18	0.36	0.694	0.14	0.136	0.55	0.809	0.09
ML diameter (cm)	0.33	18	0.28	0.30	18	0.23	0.32	18	0.23	0.26	18	0.33	0.574	0.20	0.527	0.23	0.685	0.14
2D US change on MVC																		
BN height (mm)	2.41	18	2.75	4.36	17	4.10	3.57	18	2.94	4.48	17	2.97	0.163	0.50	0.143	0.52	0.234	0.42
LP length (mm)	-9.70	18	4.60	-11.06	18	4.71	-10.84	18	5.65	-12.95	18	5.48	0.276	0.38	0.034	0.76	0.583	0.19
2D US change on MVM																		
BN height (mm)	-9.71	19	4.00	-8.90	17	4.33	-8.40	19	3.73	-8.46	17	4.04	0.77	0.11	0.041	0.73	0.296	0.36
LP length (mm)	6.00	17	7.34	5.05	18	5.08	4.63	17	5.33	2.84	18	3.77	0.444	0.27	0.004	1.08	0.471	0.26

RI-SUI: running-induced stress urinary incontinence; MVC: maximal voluntary contraction; MVM: maximal Valsalva maneuver; 2D: 2 dimensional; 3D: 3 dimensional; BN: bladder neck; LP: levator plate; US: ultrasound; AP: anteroposterior; ML: mediolateral; mm: millimeters; cm: centimeters; SD: standard deviation.

*** negative values indicate a shortening of levator plate or a caudal descent of BN height. Significant differences ($\alpha = \leq 0.05$) are indicated in bold.

4.4.3 Intravaginal dynamometry outcomes

The dynamometry outcomes obtained from the MVC and passive tissue elongation before and after the run are presented in **TABLE 4.2**. No significant between or within group differences were found; however moderate effect sizes were observed for the interaction between group (RI-SUI vs controls) and time (before vs after the run) for strength (relative peak force; $d=0.66$) and power (rate of force development; $d=0.61$) achieved during peak MVC. While the strength and power achieved during the MVC tended to increase after the run among runners without RI-SUI, relative to their baseline, power tended to decrease, and strength remained unchanged among runners with RI-SUI after the run. During passive tissue elongation, the stiffness and relative peak force tended to be lower in runners with RI-SUI compared their continent counterparts ($p=0.056$; $d=0.77$ and $p=0.169$; $d=0.54$ respectively) and tended to decrease after the run for both groups ($d=0.47$ and $d=0.47$ respectively). Missing data as reported in TABLE 4.2 was due to technical difficulties with the hardware of the intravaginal dynamometer which prevented the researcher from collecting a complete data set in some cases.

4.4.4 Post-hoc comparison of runners with RI-SUI whose leakage was provoked vs those whose leakage was not provoked during the running protocol

As presented in **TABLE 4.4**, there was a large between-group (those with RI-SUI who leaked vs those with RI-SUI who did not leak) and time (before vs after the run) interaction effect in terms of the peak position of the BN during the MVC ($p=0.045$; $d=0.92$). There was also a large between-group effect for LP length at rest and LP length during peak MVM ($p=0.013$; $d=1.40$ and $p=0.039$; $d=1.12$ respectively). Indeed, among those with RI-SUI whose leakage was provoked during the running protocol, the BN position sat more caudal within the pelvis, particularly after the run, and the LP was more elongated. There were also large effect sizes when relative peak force ($p=0.210$; $d=0.80$) and stiffness ($p=0.224$; $d=0.78$) recorded during

passive tissue elongation were compared between the groups—the runners with RI-SUI whose leakage was provoked during the running protocol tended to demonstrate lower resistance of their paravaginal tissues to passive stretch imposed through intravaginal dynamometry.

Table 4.4 The effects of running on intravaginal dynamometry and ultrasound imaging outcomes in runners with running-induced stress urinary incontinence, stratified by whether leakage was provoked by the running protocol or not.

	Before the run						After the run						Between-group		Within-group		Interaction	
	Did not leak			Leaked			Did not leak			Leaked								
	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD	p-value	Cohen's d	p-value	Cohen's d	p-value	Cohen's d
Dynamometry outcomes during MVC																		
Relative peak force (N)	4.38	5	1.56	4.08	7	1.19	4.37	5	1.50	4.02	7	1.36	0.689	0.26	0.860	0.11	0.902	0.09
Rate of force development (N/s)	11.66	5	3.18	10.89	7	4.55	11.35	5	4.23	9.53	7	5.42	0.624	0.32	0.254	0.77	0.463	0.48
Dynamometry outcomes during passive elongation																		
Relative peak force (N)	11.49	5	6.04	8.61	8	2.36	11.07	5	4.95	8.48	8	1.62	0.210	0.80	0.587	0.34	0.770	0.18
Stiffness (N/s)	29.48	5	14.37	23.02	8	8.63	29.27	5	11.51	22.56	8	5.58	0.224	0.78	0.884	0.09	0.957	0.00
3D US measurements at rest																		
Area (cm2)	17.04	6	6.53	18.53	11	4.85	17.48	6	5.55	19.59	11	5.05	0.513	0.35	0.066	1.02	0.433	0.41
3D US measurements on MVM																		
Area (cm2)	21.62	5	7.56	21.80	11	5.40	21.64	5	8.57	22.08	11	5.24	0.926	0.06	0.831	0.11	0.851	0.11
2D US measurements at rest																		
BN height (mm)	15.80	6	2.27	16.44	11	4.20	14.94	6	3.30	13.37	11	4.66	0.812	0.13	0.006	1.64	0.094	0.92
LP length (mm)	51.18	6	6.88	58.12	12	6.60	53.48	6	5.63	63.28	12	7.21	0.013	1.40	0.026	1.22	0.363	0.47
2D US measurements on MVC																		
BN height (mm)	18.14	7	3.88	20.58	10	3.79	18.76	7	3.06	18.58	10	5.11	0.572	0.30	0.268	0.59	0.045	1.13
LP length (mm)	42.90	7	6.81	47.19	11	5.51	41.59	7	5.62	47.21	11	5.18	0.085	0.92	0.283	0.56	0.270	0.57
2D US measurements on MVM																		
BN height (mm)	8.89	6	2.68	6.46	11	4.19	7.71	6	2.48	4.23	11	4.52	0.141	0.80	0.003	1.84	0.290	0.57
LP length (mm)	56.23	6	11.25	63.17	12	8.78	55.55	6	7.42	66.51	12	8.00	0.039	1.12	0.478	0.36	0.288	0.55

MVC: maximal voluntary contraction; MVM: maximal Valsalva maneuver; 2D: 2 dimensional; 3D: 3 dimensional; BN: bladder neck; LP: levator plate; US: ultrasound; N: Newtons; N/s: Newtons per second; mm: millimeters; cm: centimeters; SD: standard deviation.

Significant differences ($\alpha = \leq 0.05$) are indicated in bold.

4.5 Discussion

Both runners with and without RI-SUI experienced significant transient changes, particularly in the morphology of their pelvic floor as measured by USI after they completed a 37-minute treadmill running protocol. The changes induced by running appear to predominantly affect the passive support system, as evidenced by the larger area and AP diameter of the levator hiatus, the more caudal position of the BN, and the elongated LP observed in quiet standing after running compared to baseline. Although PFM function, as measured by intravaginal dynamometry, was not significantly affected by the run, the directionality of the observed effects was consistent with the morphological changes. Specifically, the relative peak force and stiffness measured during passive tissue elongation tended to be lower after the run than before the run. And, while differences were not statistically significant, the runners who experienced RI-SUI tended to generate less power after running than before the run, while their strength (relative peak force) did not change. Conversely, the runners without RI-SUI, tended to generate greater force and more power after the run compared to before the run. These findings suggest that an acute bout of running results in strain of the passive tissues within the pelvis, which was observed in all female runners, regardless of whether they experience urine leakage during running. Such changes are likely related to transient changes in the viscoelastic characteristics the tissues after an episode of repetitive loading—the tissues likely return to their prestressed state assuming there is no underlying damage, however, the cumulative effects of repeated running bouts should be investigated.

4.5.1 Ultrasound imaging

Running caused significant transient morphological changes in pelvic morphology, as measured by 2D and 3D USI, mainly reflecting elongation of the passive supporting structures.

Indeed, the passive support structures appeared to be equally affected by the activity in runners both with and without RI-SUI. Based on these findings, it is plausible that the initial morphological features of the levator hiatus, BN, and LP may serve as a predisposing factor for the development of RI-SUI over the course of a run. It is possible that some threshold exists for the levator hiatus area, LP length, BN height, or a combination of these factors beyond which the passive support to the urethra is no longer sufficient to support and compress it between the anterior vaginal wall and the pubic symphysis to prevent urine leakage. Consistent with this theory, a recent study investigating the likelihood of SUI symptoms being cured by a PFM training intervention found that a resting BN position lower than 14.3 mm in standing, as measured on 2D USI, was predictive of treatment failure (Brooks et al., 2021). In the current study, continent runners had a resting BN height that was above this threshold both before and after the run (17.98 mm before vs 14.66 mm after), however, the BN of runners with RI-SUI dropped below this threshold after the run (16.22 mm before vs 13.92 mm after). While the BN may descend over the course of a run in all female runners, leakage may occur when the BN position ultimately reaches some failure point (Brooks et al., 2021). This theory is consistent with findings that athletes most often leak urine towards the middle and end of a training session (Carvalhais et al., 2018).

The significant increase in the extent of shortening of the LP observed during the MVC after the run, and the significant decrease in the extent of lengthening of the LP during the MVM after the run are likely due to a transient increase in the length of the LP. With a longer LP length at rest, the LP had to shorten more during the MVC to achieve the same end-MVC length observed before the run, and similarly the LP did not have as much room to lengthen during MVM before it reached its ultimate endpoint. As with the LP, the significant reduction in both groups in the extent of BN descent observed during the MVM after the run can be attributed to

the lower resting position of the BN after the run which was already close to its maximal descent.

4.5.2 Intravaginal dynamometry

Although not significant, the trends observed on dynamometry are worth discussing as the effect sizes were moderate to large, yet these results should be interpreted with caution. Runners with RI-SUI demonstrated a 9% reduction in the contractile power of their levator ani muscles after running, while their strength remained unchanged. In contrast, the runners without RI-SUI, tended to have higher strength (14% increase) and power (8% increase) after the run compared to before the run. These results align somewhat with previous findings among nulliparous females with mild SUI, where a mean reduction in maximal vaginal closure pressure induced by MVC of the levator ani muscles was substantive (-20%) but not significant following a 90-minute exercise session that included 20 minutes of running (Ree et al., 2007). Also, in line with the current findings, there were no changes in vaginal resting pressure nor the time over which an MVC could be sustained (i.e., static endurance) following the exercise session (Ree et al., 2007). The current results are also consistent with findings that, following a 20-minute AMRAP (as many repetitions as possible) workout, strenuous exercisers (27.7% with symptoms of urine leakage) demonstrated significantly more vaginal descent and significantly lower vaginal resting pressure (Middlekauff et al., 2016), without concurrent changes in maximal vaginal closure pressure during MVC after the exercise (Middlekauff et al., 2016). A control group of nonstrenuous exercisers (8.57% with symptoms of urine leakage) completed a 20-minute walk, and no differences were observed between the strenuous exercisers and the control group in terms of effect on pelvic organ support and vaginal closure pressure despite the different intensity of the exercise (Middlekauff et al., 2016). Both the current study and these previous results reinforce the idea that an acute bout of exercise may have a greater impact on passive pelvic organ support rather than PFM contractile function.

While not significant, stiffness and peak passive force measured through dynamometry tended to be compromised in the runners with RI-SUI relative to their continent counterparts, which align with the observed morphologic changes in all runners. While both groups demonstrated similar reductions in stiffness and peak passive forces after completing the running protocol, the group with RI-SUI had lower absolute stiffness and lower peak passive forces after the running protocol. Further, the runners with RI-SUI whose leakage was provoked during the running protocol appeared to experience greater strain compared to those with RI-SUI whose leakage was not provoked. More research with a larger sample size is needed to establish the contribution of the loss of passive tissue stiffness in RI-SUI.

4.5.3 Limitations

This study focused on experienced female runners and thus the findings may not be generalizable to infrequent runners. The sample included middle-aged nulliparous and parous, mostly Caucasian, healthy females. While the outcomes of this investigation might be transferable to other athletes who engage in running as a component of other physical activities, the results may not be applicable to all athletes. While the runners without RI-SUI selected a faster treadmill speed than their incontinent counterparts (10.8 km/h versus 9.7 km/h), step counts during the running protocol were not different between the groups, suggesting that, while loading may have been higher in the continent group, the pelvic tissues were exposed to a similar number of loading cycles in both groups with comparable levels of exertion (15-16 on the Borg Scale). Indeed, had the runners with RI-SUI run at the same intensity as their continent counterparts, the observed changes may have been greater.

Vaginal birth is a known risk factor for SUI, and it impacts the morphology and functioning of the PFMs. Although efforts were made to balance parity as a dichotomous variable between the recruited groups, there was a higher proportion of female runners with multiple childbirths in the RI-SUI category in contrast to those without. Nonetheless, an equal

number of participants in both groups (n=4) exhibited levator avulsion (partial or complete). Additional alterations in the pelvic floor linked to parity such as nerve damage might have played a role in affecting the findings of this investigation.

Neural, metabolic, and vascular components of the continence system could impact differences in the force generation capacity of the PFMs after the run; however, these were not assessed in the present study. Indeed, although PFM surface electromyography (EMG) was pilot tested as an outcome to be measured concurrently with intravaginal dynamometry in this study, it was deemed not to be feasible, as the arms of the dynamometer caused significant motion artifact in the EMG signals, intravaginal electrodes were dislodged by the dynamometer arms, and adhesive electrodes lifted, particularly after the run, due to perspiration, urine and/or vaginal secretions.

Not all runners with RI-SUI leaked urine during the protocol. A longer or more strenuous protocol may have induced greater changes in morphology and function than was observed here. Although the sample size was small, this hypothesis is supported by the exploratory post-hoc analysis presented in TABLE 4. Among the runners with RI-SUI, those whose leakage was provoked during the running protocol, findings point to greater reductions in pelvic organ support compared to those with RI-SUI who did not experience leakage during the protocol. Although participants were evaluated quickly after the running protocol (within 15 minutes), it is possible that the passive PFM tissue properties may have recovered somewhat by the time the passive tissue elongation was performed. As such, the extent of tissue strain induced by the running protocol may be larger than that reported here.

A final limitation of this study is the extent of missing data that resulted from hardware failure in the intravaginal dynamometer and poor image quality during USI, which resulted in a smaller sample size for some outcomes. The interpretation of the results is also subject to the limitations of the instruments themselves. For instance, while intravaginal dynamometry is

considered a gold standard for the measurement of PFM active and passive tissue properties, it remains a coarse measurement as it is influenced by all closure forces acting on the dynamometer arms (El-Sayegh et al., 2023; Worman et al., 2023). USI measurements can be influenced by changes in the angle of the transducer during acquisition and the incorrect identification of landmarks (Worman et al., 2023).

That said, the innovative approach used in this study to investigate the effects of an acute bout of running on active and passive pelvic floor support structures contributes to our understanding RI-SUI. The findings point to practical approaches that focus on enhancing pelvic floor support such as PFM training and the use of pessaries to effectively mitigate or prevent symptoms of athletic incontinence in females. If pelvic floor support is enhanced prior to an acute bout of running, it might prevent the pelvic structures from descending below a critical threshold that leads to the failure of the continence system over the course of a run.

4.6 Conclusion

The findings of this study indicate that a 37-minute bout of treadmill running causes transient strain in the passive tissues in the pelvic floor, leading to significant loss of pelvic organ support among runners with and without RI-SUI. The findings revealed no evidence to support the hypothesis that the running protocol induced contractile fatigue in the PFMs. Future research should aim to investigate the time course of morphologic changes that occur during running, as well as recovery profiles.

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Chapter 5 The Feasibility of Using an Intravaginal Intra-Abdominal Pressure Sensor During Running to Evaluate Pelvic Floor Loading and Its Association with Running-Induced Stress Urinary Incontinence: An Observational Cohort Study

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Authors' Contributions statement:

ME Bérubé: Project development, Data collection, Data processing, Data analysis, Manuscript writing, Revision process

S Niederauer: Project development, Data processing, Revision process

R Graham: Project development, Data processing, Revision process

R Hitchcock: Project development, Revision process

L McLean: Project oversight, project development, Project Infrastructure and Funding, Data analysis, Manuscript writing, Revision process

5.1 Abstract

Introduction & hypothesis:

The aim was to investigate the feasibility of using an intravaginal intra-abdominal pressure (IAP) sensor worn by female runners during running to evaluate pelvic floor loading, and the association between IAP and running-induced stress urinary incontinence (RI-SUI)

Methods:

Twenty-eight female runners participated in this cross-sectional study (15 RI-SUI and 13 continent). Participants completed a 37-minute treadmill running protocol instrumented with an intravaginal sensor measuring IAP, and a skin mounted accelerometer measuring pelvic accelerations. Linear regression analyses evaluated the relationship between IAP and pelvic acceleration. One-way ANOVAs assessed the impact of running speed on IAP. Sensor dislodgement was recorded, and effect sizes (Cohen's d) were calculated for the comparison of IAP and accelerometry outcomes between runners with and without RI-SUI.

Results:

IAP showed high variance and the sensor was expelled in almost 15% of participants. Positive associations were found between pelvic acceleration and both absolute peak and normalized IAP but explained only between 12.0% and 18.6% of the variance in the models. Pelvic acceleration during running was not associated with cumulative IAP. Peak IAP significantly increased with running speed. While IAP tended to be higher in runners with RI-SUI compared to continent runners (Cohen's d between 0.14 and 0.74), pelvic accelerations tended to be lower (Cohen's d between 0.02 and 0.55).

Conclusion:

There is high variance in IAP recorded during running using an intravaginal sensor. Faster speeds increase pelvic floor loading. Runners with RI-SUI may experience higher IAP than continent runners, warranting investigation. Recruitment should include 15% data loss rate due to sensor expulsion.

5.2 Introduction

Pelvic floor loading is thought to be a key factor in the development of stress urinary incontinence (SUI) symptoms during exercise (Bo & Nygaard, 2020). This hypothesis is primarily based on the observation that symptoms of urine leakage are highly prevalent during high-impact activities, particularly among female runners (Almousa & Bandin Van Loon, 2019; Pires et al., 2020; Rebullido et al., 2021; Teixeira et al., 2018). However, there is scant existing data on this topic, and findings are inconsistent (Bo & Nygaard, 2020). Runners report that urine leakage tends to occur after some period of running without leakage, suggesting a cumulative effect of pelvic floor loading (Carvalhais et al., 2018). Indeed, acute running bouts seem to adversely affect pelvic organ support in runners, evidenced by a larger levator hiatus, a longer levator plate, and a lower bladder neck observed after running among runners both with and without running-induced (RI)-SUI when compared to measures made prior to the run (Bérubé & McLean, 2024). Peaks or cumulative pelvic floor loading during repetitive high impact activity may increase the risk of experiencing RI-SUI, but this has not been evaluated empirically.

Intra-abdominal pressure (IAP) is considered an important factor in pelvic floor loading. When performing dynamic tasks including sit-to stand, walking, lifting, fall recovery, and jumping, the magnitude of pressure measured by an IAP sensor located within the posterior fornix appears to be influenced by hip acceleration, respiration volume, and flexion moment of the trunk and abdominal wall (Niederauer et al., 2023), which, combined, appear to account for 60% of the peak IAP. During upright activities, pressure measurements at the posterior fornix likely reflect a combination of IAP and gravitational loading on the pelvic floor. Studies have reported high variability in peak IAP measured during physical tasks when a sensor is located in the posterior fornix (Coleman, Hamad, et al., 2015; Coleman, Nygaard, et al., 2015; Hsu et al., 2018). Some have reported an increase in IAP during the transition from walking to running

(Egger et al., 2015; Shaw et al., 2014) and increases in IAP with increased walking speed and inclination (de Gennaro et al., 2019; Shaw et al., 2014). A strong positive correlation ($r=0.7220$) was found between IAP and pelvic acceleration measured during walking, and the authors concluded that pelvic accelerometry might be a valid way to estimate pelvic floor loading, yet this association may not be causal, and it has not been validated during running (de Gennaro et al., 2019).

Given that females limit the intensity of their physical activity because of lower urinary tract symptoms (Dakic et al., 2021), there is an urgent need to understand the pathomechanics at play to guide the development of biomechanical interventions to mitigate urine leakage. Measuring pelvic floor loading during running using an IAP sensor placed within the posterior fornix may help us to fill this knowledge gap. Yet first we must determine the feasibility of this approach, through understanding how to interpret IAP outcomes when measured during running. A first step is to understand the contribution of running parameters (speed, pelvic acceleration) to peak and cumulative IAP measured in this way, and the stability of the sensor across the running task.

The aim of this exploratory study was therefore to determine the feasibility of using an intravaginal IAP sensor worn while running to investigate differences in pelvic floor loading between female runners with and without RI-SUI. The objectives were (1) to determine the relationship between vector (Euclidean norm) and vertical pelvic accelerations observed during running and pelvic floor loading measured through an intravaginal IAP sensor, (2) to evaluate the impact of running speed on pelvic floor loading measured through the intravaginal IAP sensor, (3) to evaluate the stability of intravaginal IAP sensor measurements made during running at two fixed speeds before and after a 30-minute steady-state treadmill running

protocol, (4) to observe the rate of sensor dislodgement throughout the protocol, and (5) to estimate the effect sizes associated with differences in IAP and acceleration measures of pelvic floor loading during running. The outcomes of this research contribute to the development of robust measures to elucidate the pathomechanics associated with RI-SUI among females.

5.3 Methods

5.3.1 Design

This observational, cross-sectional study received approval from the local institutional research ethics board prior to recruitment. Recruitment and data collection were completed between June 2019 to March 2021, with a pause between March 2020 and January 2021 due to laboratory closures caused by the COVID-19 pandemic. All participants provided written informed consent prior to completing any aspect of the protocol.

5.3.2 Participants

Experienced runners assigned female at birth, over 18 years of age and with no known risk factors related to physical activity were recruited from the local community through local running groups and physiotherapy clinics. Volunteers were required to meet the following exposure criteria: run at least 5 km in under 50 minutes twice a week, having sustained an average running distance of >10 km per week for a minimum of one year. During the telephone screening interview, runners were classified as continent if they self-reported never having experienced urine leakage during running and not leaking urine during activities of daily living. Conversely, runners with RI-SUI were required to self-report leakage at least 2 to 5 times per month while using mitigation strategies (voiding their bladder before/during the run, running at a slower pace, avoiding hills, etc.) and to leak more than once per week when not using these strategies. Participants who experienced occasional instances of urinary urgency during running

without any associated leakage were included, however they were excluded if they experienced leakage related to urgency during running. Additional exclusion criteria were: a history of urogenital surgery or neurological disorders, self-reported symptoms of energy deficiency as measured by the Low Energy Availability in Females Questionnaire (LEAF-Q) (Melin et al., 2014), pregnancy or in the first postpartum year, pelvic organ prolapse caudal to the hymen on a maximal Valsalva maneuver (MVM) performed in a standing position, or pelvic pain experienced to the extent that they were not able to insert a vaginal tampon. After providing written informed consent, all eligible participants provided demographic information including age, parity, obstetrical history (i.e. vaginal vs Caesarean section, use of forceps), their leakage profile during running, and menopausal status. They were then asked to complete the International Consultation on Incontinence - Female Lower Urinary Tract Symptoms Long Form module (ICIQ-FLUTS) and the International Physical Activity Questionnaire (IPAQ) (Hagströmer et al., 2006).

5.3.3 Laboratory assessment

Participants with a menstrual cycle were asked to attend during the follicular phase of their menstrual cycle, determined as the first week following the cessation of menstrual bleeding. The laboratory assessment was performed by a registered physiotherapist trained in the assessment and treatment of pelvic health conditions, and who had over 5 years of experience in this practice area prior to data collection. She was trained to use the IAP sensor. The participants inserted a validated (Coleman et al., 2012; Hsu et al., 2012; Rosenbluth et al., 2010), reliable (Egger et al., 2015), sterilized, and calibrated (0 to 350 cm H₂) IAP sensor into the posterior fornix of their vagina. Adequate positioning of the device was confirmed by the physiotherapist using digital palpation. The participants were then instructed to don their underwear and a pair of running shorts to hold all wires in place. IAP sensor data were acquired

at a sampling rate of 40Hz and stored on an SD card within an instrumented module that was secured to the left iliac crest with adhesive tape. To ensure that the intravaginal sensor was securely located in the upper third of the vagina, the participants were instructed to stand up and perform three maximal effort coughs and three maximal Valsalva maneuvers (MVM). To ensure comparability of IAP measurements between subjects, the IAP data recorded during running were normalized to that recorded during vertical jumping. The participants were asked to perform three vertical jumps from the ground, as this task is less effort dependent than coughing or Valsalva. The instruction given was: "When I signal you, jump as high as you can, as if you are trying to touch the ceiling." During the tasks, if the sensor descended below the levator hiatus, it was reinserted, and the process was repeated. If the sensor still descended, the participant was removed from the study.

An accelerometer (*MetaMotionR*, *Mbientlab Inc.*) with a range of ± 16 gravitational units (g) was adhered directly to the skin over the upper border of the left mid-iliac crest and was used to record raw acceleration values in the vertical, anteroposterior and mediolateral directions at a sampling rate of 100 Hz.

Participants moved to the treadmill (NordicTrack Commercial 2450) and began by walking, increasing the belt speed to 7 km/h. They jogged for 2 minutes, then increased the speed to 10 km/h and ran for 2 min, then increased the speed to 15 km/h and ran for 2 minutes. The participants could discontinue running at 15 km/h if they did not feel safe or if they did not have to capacity to sustain this speed. In these cases, they ran at their fastest comfortable pace for the remainder of the 2-minute period. The participants were then asked to choose a speed to run at for 30 minutes, at an intensity which they deemed to be hard (level 15-16 on the Borg Scale). After 30 minutes of running, the participants ran for 30 seconds at 10 km/h then at 7 km/h. IAP data were logged into the instrumentation module throughout the protocol while samples of pelvic acceleration were taken in bursts of 15-second duration during each running

condition. If a participant felt short of breath or discomfort during the running task, they could slow their speed for one minute before resuming the same running speed. Participants were not restricted from drinking water during the running protocol. After the protocol, the researcher removed the accelerometer and inspected the IAP sensor to record whether it was still located within the posterior fornix of the vagina before removing it.

5.3.4 Outcomes

All raw IAP data were inspected for noise interference through visual inspection of the time series and power spectra. No filtering was deemed necessary. The mean **IAP jump** value was calculated for the vertical jump normalization task as the average of three trials using the net IAP value (maximal value during the jump and minimal value before the jump) (Dietze-Hermosa et al., 2020). For IAP data collected during the running protocol, IAP peaks were identified using a custom MATLAB program. Peaks were required to be at least 0.2 seconds apart to reduce sampling bias (**FIGURE 5.1**). The highest and lowest IAP values obtained from each of the different running speeds (7 km/h at the start and end of the protocol, 10 km/h at the start and end of the protocol, 15 km/h at the start of protocol, self-selected speed) were used to compute the **net mean peak IAP** at each speed and time point where applicable (Hamad et al., 2013). The net mean peak IAP was normalized to become the **relative net mean peak IAP** obtained across each running speed, calculated as a percentage of the mean IAP recorded during vertical jumping (IAP jump).

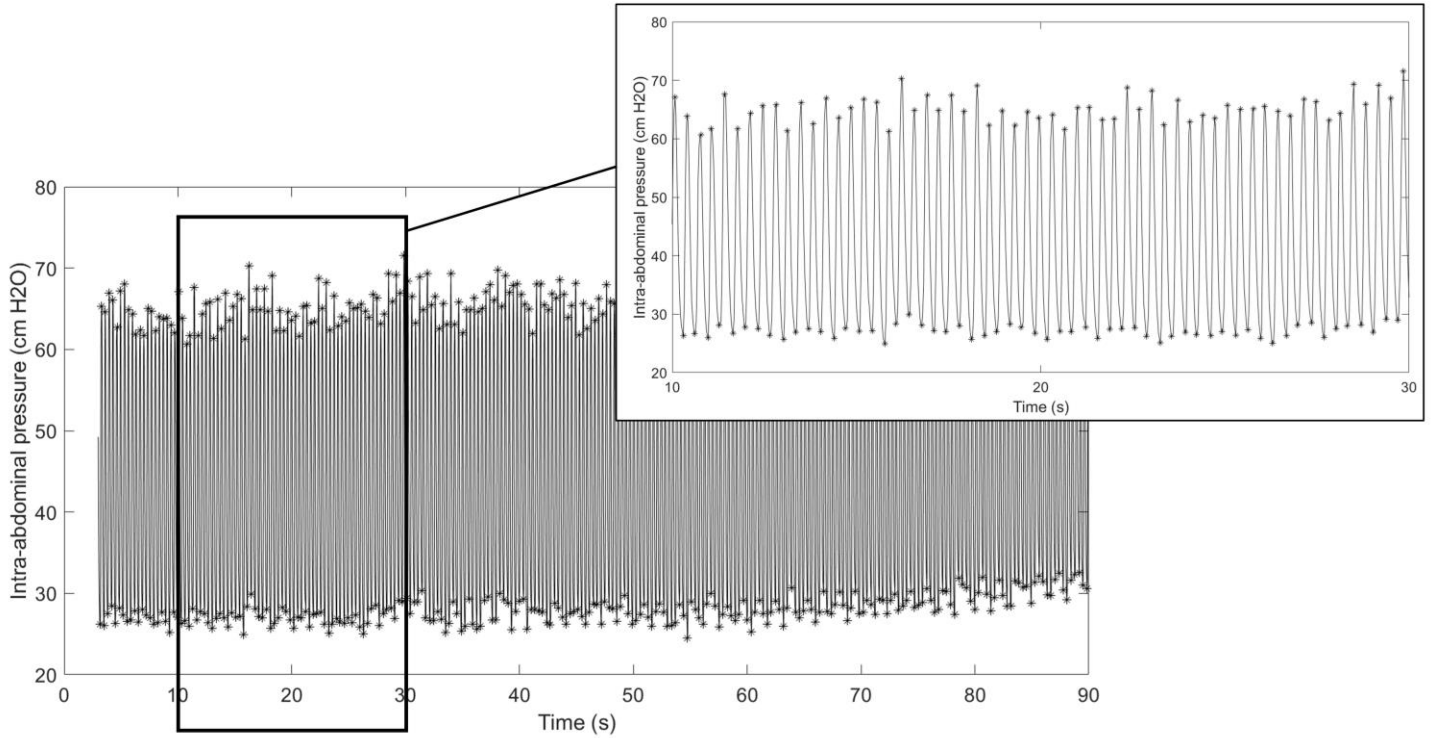


Figure 5.1 Raw intra-abdominal pressure data (centimeters of water (cmH₂O)) vs running time (seconds) at a speed of 7 km/h. The Asterisks represent all the maxima and the minima that were used to estimate the average net mean peak intra-abdominal pressure (average of the local maxima minus average of the local minima). The zoomed-in panel shows a detailed view of intra-abdominal pressure over a 20-second interval.

To consider cumulative effects, the IAP time series were integrated through calculating the area under the curve (AUC) over 10 s at each running speed and time where applicable (Hamad et al., 2013) [i.e., 7 km/h (start/end), 10 km/h (start/end), 15 km/h (start)], and over 10 minutes for the self-selected speed].

Using a separate custom MATLAB program, raw pelvic acceleration data were filtered using a second order dual-pass Butterworth filter with a 6 Hz cut-off. The vertical acceleration (a_y) and the vector acceleration (Euclidean norm) $|\vec{a}|$ (Equation 5.1, where a_x , a_y and a_z represent

acceleration values in the x (anteroposterior), y (vertical), z (mediolateral) planes, respectively) were averaged over 10 consecutive steps for each running speed using the peak acceleration values from each step.

$$|\vec{a}| = \sqrt{a_x^2 + a_y^2 + a_z^2}. \quad \text{Equation 5.1}$$

5.3.5 Statistical Analysis

Statistical models were generated using IBM SPSS version 28, and $\alpha=0.05$ was used for all tests. The IAP and acceleration outcomes were tested for normality using the Shapiro-Wilk test.

For the demographic outcomes, parametric (t-test) or non-parametric (Mann-Whitney U) analyses were applied as appropriate to assess group differences between runners with and without RI-SUI while chi-square (X^2) tests were used to analyze group differences in dichotomous variables. Descriptive statistics of the IAP and acceleration measurements were calculated for each running speed separately for runners with and without RI-SUI. The standard deviation and the average range between the three trials of the IAP during the jump tasks were calculated. Regression analyses with pooled data from all participants were conducted to evaluate the relationship between pelvic accelerations (a_y and $|\vec{a}|$) and IAP outcomes (net mean peak IAP, relative net mean peak IAP normalized to vertical jumping, and IAP AUC with data from all running speeds pooled). A one-way ANOVA was used to test differences in net mean peak IAP, relative net mean peak IAP, and AUC IAP among running speeds (7 km/h, 10 km/h, 15 km/h). To evaluate the stability in the IAP outcomes across the running protocol, paired sample t-tests were carried out to compare the net mean peak IAP and normalized net mean peak IAP before and after the 30-minute run at both 10 and 7 km/h speeds. IAP jump, IAP outcomes and accelerations during running were compared between runners with and without RI-SUI using parametric (t-test) or non-parametric (Mann-Whitney U) tests as appropriate. The

coefficients of variation were calculated as well as Cohen's d effect sizes, where $0.2 \leq d < 0.5$ were considered small, $0.5 \leq d < 0.8$ were considered moderate, and $d \geq 0.8$ were considered large (Cohen, 2013). The effect sizes were then used to calculate the requisite sample size for a future study, ensuring sufficient statistical power (two-tailed power calculation using G*Power version 3.0.10; $\alpha=0.05$; $\beta=0.80$), to detect differences between runners with and without RI-SUI.

5.4 Results

5.4.1 Sample Demographic Information

Sixty-nine female runners underwent screening, among which thirty-nine were eligible to participate and successfully completed the laboratory assessment. Technical difficulties were encountered with the instrumentation module or the SD card of the IAP sensor in 5 participants, and the sensor was dislodged from the vagina during the running task in 6 participants. Ultimately, IAP data were collected from 28 participants. Sample demographic data are presented in **TABLE 5.1**. Runners with RI-SUI reported significantly higher scores on the Incontinence subscale of the ICIQ-FLUTS. Otherwise, both groups were similar across all other demographic outcomes.

Table 5.1 Demographic data for the experienced female runners

	Participants (n=28)		No SUI with running (n=13)		SUI with running (n=15)	
	Mean/n	SD or %	Mean/n	SD or %	Mean/n	SD or %
Age (years)	40.63	10.74	36.86	9.20	43.90	11.56
BMI (kg/m ²)	23.25	3.54	22.32	2.52	24.05	4.26
Waist to hip ratio	0.79	0.08	0.78	0.10	0.80	0.05
Parous	11	39	4.00	31%	7.00	47%
Use of forceps (n, %)	3	11	1.00	8%	2.00	13%
Use of suction (n, %)	1	4	0.00	0	1.00	7%
Menopause (n, %)	4	14	1.00	8%	3.00	20%
ICIQ-FLUTS total score (/48)	7.82	4.53	4.62	3.75	10.60	3.33 *
ICIQ-FLUTS F (/16)	3.21	2.06	2.54	2.11	3.80	1.97
ICIQ-FLUTS V (/12)	0.68	1.1	0.31	0.48	1.00	1.41
ICIQ-FLUTS I (/20)	3.93	3.13	1.77	2.35	5.80	2.60 *
IPAQ total activity (MET-minutes/week)	5454.04	6505.5	4028.96	2230.06	6689.10	8766.99
IPAQ sub total vigorous activities (MET-minutes/week)	1813.93	2521	1520.00	1016.40	2068.67	3416.93
Self-selected running speed (km/h)	10.15	1.68	10.66	1.21	9.71	1.99
Number of steps during running protocol	6388.7	310.26	6449.00	363.68	6340.47	275.90
Weekly running distance (km)	35.21	22.6	33.85	17.78	36.40	27.33
Running experience (years)	15.76	10.85	16.23	9.58	15.35	12.50

Significant differences ($\alpha < 0.05$) between groups are indicated by * and are in bold.

RI-SUI = running-induced stress urinary incontinence; BMI = body mass index; ICIQ-FLUTS = International Consultation on Incontinence - Female Lower Urinary Tract Symptoms Long Form module; IPAQ = International Physical Activity Questionnaire; MET = metabolic equivalent of task; km/h = kilometers per hour

The average standard deviation between the three trials of the jump was 7.64 cm H₂O and the average range was 14.32 cm H₂O. There was moderate variance in the IAP data, as demonstrated by the coefficient of variation that ranged from 0.18 to 0.35 for the net mean peak IAP, from 0.19 to 0.39 for the relative net mean peak IAP and from 0.17 to 0.22 for the AUC IAP (TABLE 5.2).

Table 5.2 Intra-abdominal pressure and accelerations outcomes between runners with and without running-induced stress urinary incontinence

	No RI-SUI					RI-SUI					Cohen's d
	Mean	SD	range	CoV	n	Mean	SD	range	CoV	n	
IAP jump (cm H2O)											
Vertical jump	85.21	21.88	59.28-138.48	0.26	13	74.52	17.45	44.39-105.84	0.23	15	0.54
Net mean peak IAP (cm H2O)											
7 km/h	41.28	7.52	30.63-55.10	0.18	13	42.66	11.99	18.40-60.62	0.28	15	0.14
10 km/h	43.20	8.27	33.71-62.53	0.19	13	45.57	12.12	22.94-68.67	0.27	15	0.23
15 km/h	48.56	11.10	33.51-76.07	0.23	12	54.19	14.44	34.22-79.45	0.27	12	0.44
SSS	41.58	8.85	25.07-58.20	0.21	12	45.64	15.96	17.06-77.42	0.35	15	0.31
Relative net mean peak (%IAP vertical jump)											
7 km/h	51.32	15.07	24.70-75.70	0.29	13	59.84	21.64	34.3-98.70	0.36	15	0.45
10 km/h	53.85	16.55	26.60-78.30	0.31	13	63.73	20.90	41.00-100.40	0.33	15	0.52
15 km/h	60.89	20.59	29.40-96.60	0.34	12	72.88	23.78	44.90-109.50	0.33	12	0.54
SSS	50.42	16.45	27.80-76.80	0.33	12	63.57	24.57	32.20-99.80	0.39	15	0.62
AUC over 10 sec (cm H20·s)											
7 km/h	176.34	30.51	133.54-224.46	0.17	13	189.95	36.79	109.34-245.77	0.19	15	0.40
10 km/h	176.22	28.27	129.68-216.69	0.16	13	195.09	32.42	139.75-239.15	0.17	15	0.62
15 km/h	188.83	42.23	129.25-292.06	0.22	12	218.09	36.29	140.37-266.30	0.17	12	0.74
AUC over 10 min (cm H20·s)											
SSS	10080.52	2077.41	6901.93-14267.44	0.21	12	11061.96	2326.04	6881.47-15339.76	0.21	15	0.44
Vector acceleration (g)											
7 km/h	3.28	0.44	2.72-3.93	0.14	12	3.18	0.40	2.58-4.01	0.13	14	0.24
10 km/h	3.58	0.52	2.73-4.25	0.14	10	3.38	0.34	2.78-3.89	0.10	14	0.46
15 km/h	3.63	0.41	2.92-4.12	0.11	10	3.64	0.50	2.76-4.38	0.14	11	0.02
SSS	3.59	0.41	2.82-4.24	0.11	13	3.44	0.41	2.75-4.23	0.12	15	0.37

Vertical acceleration (g)											
7 km/h	2.36	0.24	2.05-2.78	0.10	12	2.32	0.26	1.83-2.70	0.11	14	0.16
10 km/h	2.59	0.27	2.09-3.09	0.11	10	2.49	0.26	2.15-2.92	0.10	14	0.38
15 km/h	2.77	0.24	2.21-2.95	0.09	10	2.69	0.29	2.27-3.21	0.11	11	0.30
SSS	2.65	0.24	2.18-3.10	0.09	13	2.50	0.30	2.06-3.26	0.12	15	0.55

RI-SUI = running-induced stress urinary incontinence; IAP = intra-abdominal pressure; sec = seconds; cm H₂O = centimeters of water; cm H₂O·s = centimeters of water times second; AUC = area under the curve; n = sample size; SSS= self-selected speed; SD = standard deviation; km/h = kilometers per hour, g = gravitational acceleration, CoV= coefficient of variation

5.4.2 Relationship between IAP and pelvic acceleration

FIGURE 5.2 illustrates the moderate positive associations between net mean peak IAP and vector ($r=0.347$; $R^2=0.1202$; $p\leq 0.001$; panel A) and vertical ($r=0.432$; $R^2=0.1864$; $p\leq 0.001$; panel D) acceleration. There were moderate positive associations between relative net mean peak IAP normalized to vertical jumping and vector ($r=0.346$, $R^2=0.120$, $p<0.001$; panel B) and vertical ($r=0.421$, $R^2=0.177$, $p<0.001$; panel E) acceleration. There were no significant associations between IAP AUC and vector ($r=0.063$; $R^2=0.004$; $p=0.538$; panel C) or vertical ($r=0.159$; $R^2=0.025$; $p=0.120$; panel F) acceleration.

5.4.3 Impact of running speed on IAP

The net mean peak IAP and the AUC IAP at 7, 10 and 15 km/h are presented in **FIGURE 5.3**. There was a significant increase in net mean peak IAP with increased running speed ($p=0.01$); net mean peak IAP was higher at 15 km/h than at 7 km/h ($p=0.009$). There were no differences in IAP between the 7 and 10 km/h or between the 10 and 15 km/h speeds. Although the same trend was observed for the relative net mean peak IAP and AUC IAP, it was not significant.

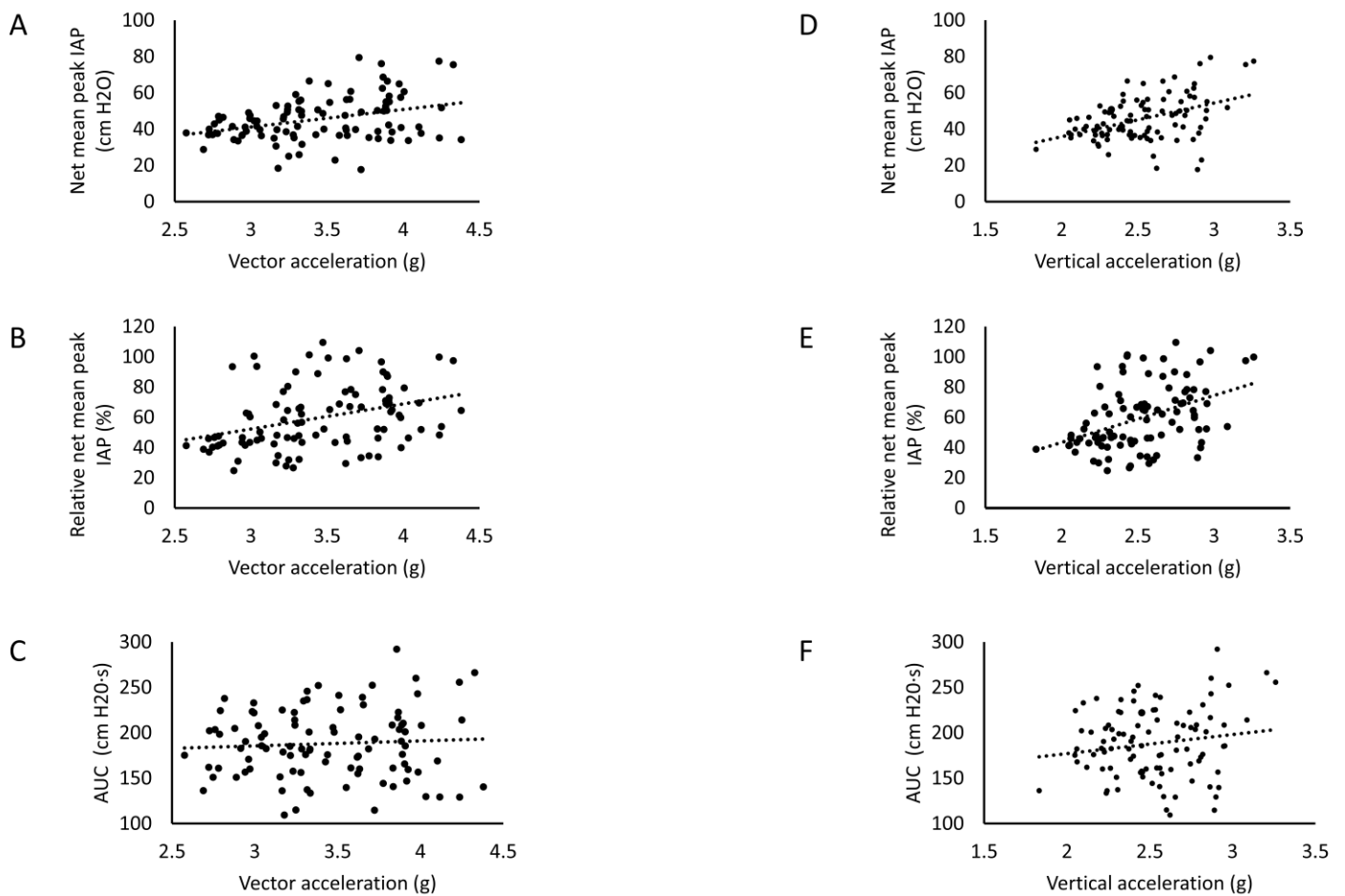


Figure 5.2 The relationship between vector acceleration and the vertical acceleration (gravitational unit=g) with net mean peak intra-abdominal pressure (IAP) in centimeters of water (cm H₂O), with relative net mean peak IAP normalized to vertical jumping and the area under the curve (AUC) in centimeters of water times second (cm H₂O·s). There were significant regressions between net mean peak IAP and vector (panel A: $r = 0.347$; $R^2 = 0.120$; $p < 0.001$) and vertical (panel D: $r = 0.432$; $R^2 = 0.186$; $p = 0.001$) acceleration and between relative net mean peak IAP during vertical jumping and vector (panel B: $r = 0.346$, $R^2 = 0.120$, $p < 0.001$) and vertical (panel E: $r = 0.421$, $R^2 = 0.177$, $p < 0.001$) acceleration. The linear regressions between the AUC IAP with the vector (panel C: $r = 0.063$; $R^2 = 0.004$; $p = 0.538$) and vertical (panel F: $r = 0.159$; $R^2 = 0.025$; $p = 0.120$) acceleration were not significant.

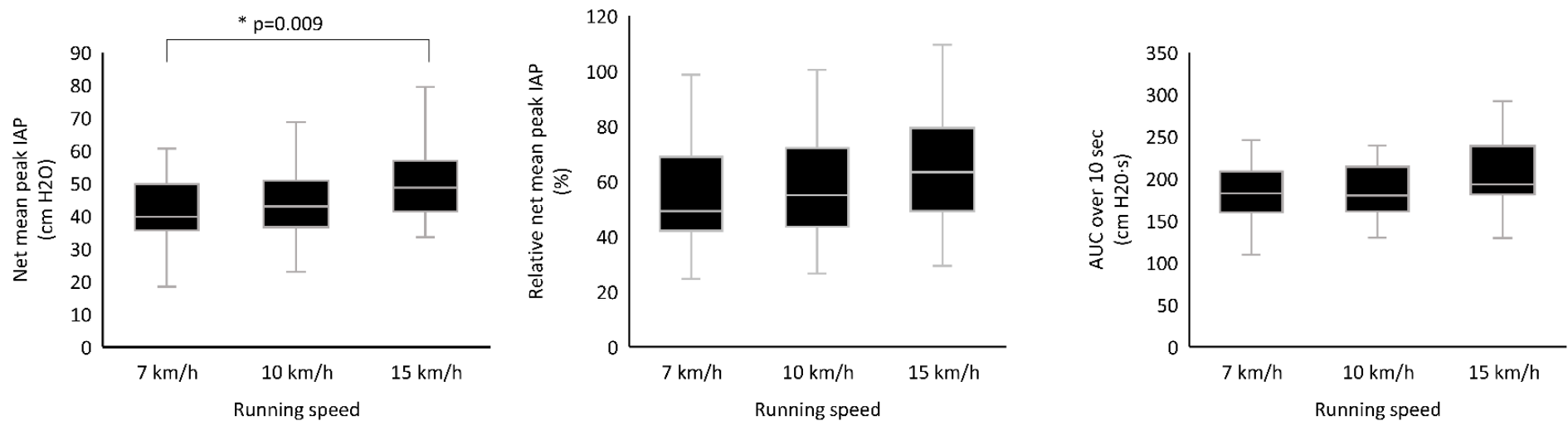


Figure 5.3 Intra-abdominal pressure (IAP) outcomes (net mean peak IAP, relative net mean peak IAP normalized to vertical jump and integrated IAP) observed during treadmill running at 7, 10 and 15 km/h. *indicates a significant difference between running speeds .cm H₂O = centimeters of water; cm H₂O·s = centimeters of water times second; AUC = area under the curve

5.4.4 Consistency in IAP measurements

No significant difference was found between the net mean peak IAP recorded during running at 10 km/h before and after the 30-minute run (mean before $\pm$ SD = 44.63 $\pm$ 10.89 cm H₂O; mean after $\pm$ SD = 43.89 $\pm$ 12.00 cm H₂O; $p=0.663$). However, the net mean peak IAP was significantly lower after the 30-minute run compared to before the run when participants ran at 7 km/h (mean before $\pm$ SD = 41.41 $\pm$ 10.51 cm H₂O; mean after $\pm$ SD = 37.93 cm H₂O $\pm$ 11.53; $p=0.038$). Similar results were observed for relative net mean peak IAP normalized to vertical jumping.

5.4.5 Sensor dislodgement

The sensor was dislodged in 3 participants with RI-SUI and in 3 continent runners, among which 5 were parous and 1 was nulliparous.

5.4.6 IAP and accelerations between runners with and without RI-SUI

TABLE 5.2 presents the IAP and acceleration outcomes observed across all running speeds for runners with and without RI-SUI. No significant differences were found between the groups for any of the outcomes. There was a wide range of the net mean peak IAP, relative net mean peak IAP and AUC measured at all speeds. The coefficients of variation (COV) for the IAP outcomes were moderate for net mean peak IAP (ranging from 0.18 to 0.35) and did not improve when normalized to the vertical jump (ranging from 0.29 to 0.39). The AUC IAP resulted in the least amount of variation ($0.16 < \text{COV} < 0.22$). As for the vector and vertical acceleration, the COVs were small, ranging from 0.09 to 0.14.

Moderate effect sizes suggest that participants with RI-SUI may experience higher net mean peak IAP, relative net mean peak IAP and AUC IAP than continent runners, especially at fast (15 km/h) running speeds ($d=0.44$ for net mean peak IAP, $d=0.62$ for relative net mean peak IAP and $d=0.74$ for AUC IAP). Overall, runners with RI-SUI tended to experience lower

accelerations compared to continent runners ($0.24 \leq d \leq 0.55$), except for vector acceleration at 15 km/h, which was similar between the groups ($d=0.02$).

Not accounting for data loss through instrumentation issues ($n=5$) among early participants which were resolved, considering that the sensor became dislodged from the vagina of 6 out of the 39 participants (approximately 15%), power calculations using the computed effect sizes suggest that a total sample size of 66 participants (33 in each group of runners) would be needed to detect between-group differences in runners with and without RI-SUI for cumulative loading (AUC IAP $d=0.44$) and 260 runners to detect differences in peak loading (net mean peak IAP $d=0.31$) at the self-selected speed.

5.5 Discussion

The results from this study show that, while feasible, measures made using an intravaginal IAP sensor located in the posterior fornix of the vagina have high variance when used to measure pelvic floor loading during running. This high variance is consistent with IAP measures made among exercising females reported by other groups that used the same sensor (Coleman et al., 2015; Hsu et al., 2018), but also with other sensors such as a wireless gastric sensor (Soucasse et al., 2022) and an intra-rectal sensor (Djivoh & De Jaeger, 2023), during a variety of exercises/tasks. Despite high variance in IAP, positive correlations have been reported between total vector pelvic accelerations and peak IAP during walking ($r=0.7220$) (de Gennaro et al., 2019), leading to a recommendation that waist-worn accelerometers are a valid method for inferring IAP during a variety of activities (de Gennaro et al., 2019). In the current study, when females ran at speeds ranging from 7 to 15 km/h, the relationship between pelvic acceleration and peak IAP was much weaker ($r=0.347$ for $|\vec{a}|$, $r=0.432$ for a_y) and does not support the use of pelvic acceleration to infer peak IAP during running. Running requires more respiratory effort, trunk rotation and abdominal muscle activation compared to walking. These variables are known to contribute to IAP (Niederauer et al., 2023), which might explain the

weaker relationship found between peak IAP and pelvic accelerations during running in this study compared to walking in other studies. The lack of significant relationship between IAP AUC and pelvic acceleration during running is consistent with previous findings during walking tasks (de Gennaro et al., 2019) and suggests that pelvic accelerations should not be used to infer cumulative loading forces experienced by the pelvic floor during running, particularly considering that we observed moderate effect sizes pointing to runners with RI-SUI experiencing higher IAP but lower pelvic accelerations during running.

IAP measured using a pressure sensor located in the posterior fornix has been validated (Coleman et al., 2012; Hsu et al., 2012; Rosenbluth et al., 2010) and found to be reliable during physical activities (Egger et al., 2015) but not specifically during running tasks, where the sensor may be more prone to descent or expulsion. While the sensor did dislodge in 6 participants, it appeared to remain in position in the others, and IAP was stable between the period before and that after the steady state run when the belt speed was 10 km/h. This finding can be considered confirmation that sensor migration was not a problem. It is unclear why IAP was lower after the run when the belt speed was 7 km/h. It is unlikely that the sensor migrated between the 10 km/h and 7 km/h conditions after the run, as these phases were only 30s in duration and the runners had already been running for 36 minutes by this point. The lower IAP measured after the run at the 7 km/h speed might be associated with viscoelastic properties of the pelvic floor tissues. Previous work suggested that an accelerometer embedded in the IAP sensor did not descend over the course of the treadmill protocol, but that pelvic floor accelerations during running were dependent on belt speed and parity (Niederauer et al., 2022). As such, changes in the properties of the pelvic floor connective tissues may have been induced by the prolonged run but were only detectable at the 7 km/h running speed. We did observe that several participants altered their running mechanics once the belt speed was slowed to 7 km/h at the end of the run,

which may have influenced IAP, but we did not record running mechanics in any quantifiable way.

We found no previous studies that examined the effect of different normalization tasks to normalize IAP data acquired during active tasks. The vertical jump task appears to be a good choice for normalization. Although the normalization of the IAP resulted in higher effect sizes between runners with and without RI-SUI compared to non-normalized IAP (net mean peak), it also increased the variance in the IAP data. Further research is needed to determine the most appropriate method for normalizing IAP data during different activities. In the case of running, it appears prudent to evaluate both non-normalized IAP and to normalize peak IAP by vertical jumping to fully explore the contributions of IAP and gravitational loading to the sensor output. Other tasks could also be considered for normalization.

Higher running speeds tended to increase net mean peak IAP, relative net mean peak IAP and AUC IAP—however, this effect was only significant for net mean peak IAP, and post-hoc testing revealed that net mean peak IAP was only different between the 7 km/h and the 15 km/h running speeds, tasks in which there is a substantial difference in locomotive effort. These results are consistent with previous work that found net mean peak IAP increased with locomotive effort when a small group of mostly nulliparous females walked at 1.7 miles per hour at a 10% grade, at 2.5 miles per hour at a 12% grade, and at 3.4 miles per hour at a 14% grade (de Gennaro et al., 2019). While the findings of the current study could lead to recommendations that runners limit their running speed to minimize IAP and consequently the risk of experiencing or developing SUI symptoms, this advice is not supported – both due to the observed high intra-individual variance in IAP and the current lack of empirical evidence that IAP exposure during running causes SUI. Indeed, while some runners experienced low IAP at high running speeds, others experienced as much as twice the IAP at that same speed.

The intravaginal IAP sensor was dislodged during running in 6 participants (3 with and 3 without RI-SUI), reducing the effective sample size from $n=34$ (after instrumentation failure in $n=5$) to $n=28$. Five out of the six participants in whom the sensor dislodged were parous. Changes in pelvic floor morphology induced by vaginal birth were likely the primary reason for this. Other studies using this sensor during pilates exercises (Coleman et al., 2015) and during a range of physical tasks (Egger et al., 2015) reported similar rates of sensor dislodgement. These results suggest that design modifications might be necessary to improve the retention rate of the sensor in parous females, particularly over an extended run. Adjustments to the sensor's size, its shape or even the texture of the silicone could enhance the fit and reduce the risk of dislodgment. Regarding the technical difficulties encountered with the sensor, the repetitive vibrations caused by running led to connector failure in several early participants. Fortunately, this issue was resolved through reinforcement of the connectors as the study proceeded. Future studies using this intravaginal IAP sensor should plan their sample size with a 15% attrition rate related to sensor loss, especially if investigating parous females over an extended run.

Based on the effect sizes computed here, peak loading (net mean peak IAP), IAP normalized to a vertical jump, and cumulative loading (IAP AUC) during an acute bout of running appear to be good candidate measures to study biomechanical factors contributing to RI-SUI, particularly investigating running speed. A next step is to evaluate the relationship between pelvic floor loading and changes in PFM morphology and function observed over the course of a running session. Because the effect sizes are moderate at best, factors other than the magnitude of the loading stress imposed on the pelvic floor during the running task likely contribute to RI-SUI and should also be considered. Factors beyond running biomechanics may also influence urethral or PFM structure, support and/or function (Bérubé & McLean, 2024),

such as the timing and amount of activation of the pelvic floor muscles observed in runners during foot strike and toe off (Moser et al., 2018; Williams et al., 2022).

5.5.1 Limitations

Although this sensor may be considered less invasive than sensors located in the rectum or stomach (Hsu et al., 2012), there are inherent limitations with its use. Indeed, the pressure outcomes recorded by the sensor during running reflect both IAP and compressive forces generated between the viscera and the pelvic floor. While this can be seen as a limitation, the resulting pressure outcomes likely reflect overall pelvic floor loading, which is the construct of interest in understanding the pathophysiology of RI-SUI.

While running is a component of numerous physical activities and sports, it is important to note that the findings from this study cannot be applied to other high-impact activities. Also, the running protocol was completed in a controlled environment on a treadmill and may not reflect how the participants would habitually run. The results from this study are generalizable only to experienced runners who are mainly premenopausal and have low BMI. Running technique, heart rate, respiration pattern, running kinematics and kinetics and abdominal muscle activation are all factors that could influence IAP experienced during running (Niederauer et al., 2023), however, these were not assessed in the present study. Although the sample size was small, it allowed us to estimate the future sample size needed to achieve adequate statistical power and to troubleshoot some concerns related to using an IAP vaginal sensor over an extended run.

5.6 Conclusion

This study explored the feasibility of using an intravaginal IAP sensor in female runners to measure pelvic floor loading during an extended treadmill run. Although there were positive associations between running speed and IAP, IAP had high variance. Similarly, the associations

between pelvic acceleration and IAP were moderate. Although the IAP was not different before and after the 30-minute run when the belt speed was 10 km/h, IAP was lower after the run when the belt speed was 7 km/h, possibly reflecting viscoelastic changes in the pelvic floor tissues or changes in running mechanics during the cool-down. Future research should anticipate a minimum attrition rate of 15% due to sensor dislodgement. The evidence is currently lacking to support biomechanical interventions for RI-SUI and future studies should aim to investigate the impact of pelvic floor loading during exercise on changes in PFM morphology and function.

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Chapter 6 Is pelvic floor loading in female runners associated with post-run changes in pelvic floor morphometry or function?

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A copy of this publication is attached in Appendix T.

Authors' Contributions statement:

ME Bérubé: Project development, Data collection, Data processing, Data analysis, Manuscript writing, Revision process

S Niederauer: Project development, Data processing, Revision process

R Graham: Project development, Data processing, Revision process

R Hitchcock: Project development, Revision process

L McLean: Project oversight, project development, Project Infrastructure and Funding, Data analysis, Manuscript writing, Revision process

6.1 Abstract

Objectives:

We aimed to investigate whether, among female runners, transient changes in pelvic floor morphometry, pelvic floor muscle (PFM) function, or pad weight gain observed after a standardized running protocol are associated with the exposure of the pelvic floor to loading during the run.

Methods:

Adult female runners with (n=19) and without (n=19) running-induced stress urinary incontinence (RI-SUI) completed a 37-minute treadmill-based running protocol with a pressure sensor placed in the posterior fornix of the vagina and a triaxial accelerometer adhered to the pelvis, and an incontinence pad adhered to their undergarment. Pelvic morphometry and PFM function were assessed before and after the run using transperineal ultrasound imaging and intravaginal dynamometry. Urine leakage volume was estimated as incontinence pad weight gain. Separate linear regression models evaluated the associations between variables representative of pelvic floor load exposure (posterior fornix sensor pressure (PFSP) and pelvic accelerations) and changes in pelvic morphometry, PFM function, and incontinence pad weight observed after the run.

Results:

After the run, the levator hiatus was larger and the bladder neck sat lower in the pelvis, yet there were no significant differences in PFM active or passive forces measured using dynamometry. These changes were not different between those with and those without RI-SUI. Higher pelvic accelerations were associated with greater reductions in passive PFM stiffness after the run ($R^2 = 20\text{--}27\%$), but not with changes in pelvic morphometry. No associations were found between any measures of pelvic floor load exposure and changes in PFM force-generating capacity. Among runners with RI-SUI, greater pad weight gain occurred among those who ran with slower vector accelerations ($R^2 = 0.27$).

Conclusion:

The magnitude of pelvic floor loading experienced during running does not appear to influence the transient loss in static pelvic organ support observed after running nor urine leakage volume.

Key Words: *intra-abdominal pressure, pelvic floor, posterior fornix sensor pressure, running, urinary incontinence, accelerations, biomechanics*

6.2 Introduction

Running is a popular activity and is a component of many sports. However, a significant number of female runners report discontinuing this form of exercise due to prevalent lower urinary tract symptoms (Dakic et al., 2021), mainly stress urinary incontinence (SUI) (Almoussa & Bandin Van Loon, 2019; Pires et al., 2020; Rebullido et al., 2021; Teixeira et al., 2018). Exposure to high-impact forces during activities such as running has been proposed as a contributor to incontinence experienced during athletic activities (Cardozo et al., 2023; Falah-Hassani et al., 2021). High intra-abdominal pressure (IAP) has also been hypothesized to lead to symptoms of SUI during athletic activities (Bérubé & McLean, 2024; Bo & Nygaard, 2020; Chisholm et al., 2019; de Melo Silva et al., 2020; Gan & Smith, 2023; Karmakar & Dwyer, 2018; Nygaard & Shaw, 2016b; Shaw & Nygaard, 2017).

Few studies on exercise-induced SUI have focussed on runners. A recent study found that a 37-minute run induced a loss of passive support without concurrent pelvic floor muscle (PFM) fatigue (Bérubé & McLean, 2024). Another study found that after performing a half-marathon, female runners experienced fatigue-related changes in PFM function including strength, endurance, and ability to complete repeated contractions (de Mendonça et al., 2023). De Melo et al. investigated biomechanical correlates of urinary incontinence among runners, finding no differences in running mechanics between runners with and without UI (de Melo Silva et al., 2020). They also found no association between the severity of leakage experienced during running and these running mechanic parameters (de Melo Silva et al., 2020). Similar results were found in a sample of postpartum runners where, during a 7-minute treadmill run, there was no evidence of an association between symptoms of pelvic floor dysfunction and both running kinetics and pelvic accelerations (Coltman et al., 2025).

Pressure measured by a sensor positioned within the posterior fornix of the vagina has been theorized to reflect pelvic floor loading (Coleman, Hamad, et al., 2015; Coleman, Nygaard, et al., 2015; de Gennaro et al., 2019; Hsu et al., 2017; Shaw et al., 2014). Such sensors have been used to infer pelvic floor loading in groups of females performing different physical activities (Coleman, Hamad, et al., 2015; Coleman, Nygaard, et al., 2015; de Gennaro et al., 2019; Hsu et al., 2017; Shaw et al., 2014). Pressure sensor data have, however, been highly variable among individuals who perform different exercise activities. The sensor measures higher pressure with tasks that increase IAP (abdominal wall muscle contraction, higher respiration volume and greater trunk flexion) and those associated with inertial loading (higher pelvic acceleration) (Niederauer et al., 2022) yet it remains unclear how exposure of the pelvic floor to these forces affect pelvic organ support or PFM function. The magnitude of accelerations experienced by the pelvis during running likely reflects the magnitude of mechanical stresses experienced by the PFMs and connective tissues related to inertial loads and ground reaction forces being transmitted up the kinetic chain (de Gennaro et al., 2019). Such mechanical stress may lead to tissue strain, and, consequently, a loss of pelvic organ support. Currently it is not clear how exposure to loading during running ultimately contributes to urine leakage among females. Understanding these relationships will allow us to explore biomechanical interventions to prevent or alleviate symptoms of SUI experienced by females during physical activities such as running.

The aim of this study was to determine, among experienced female runners, if the magnitude of loading experienced by the pelvic floor tissues (inferred both through pressure recorded by a sensor placed in the posterior fornix and through pelvic accelerations) over the duration of a standardized treadmill running protocol is associated with the extent of observed changes in pelvic floor morphometry or PFM function observed after the run. A second aim was to assess if the extent of urine leakage measured among runners with running-induced stress

urinary incontinence (RI-SUI) is associated with the magnitude of pelvic floor loading experienced during running. Our primary hypothesis was that greater pelvic floor loading would be associated with greater reductions in pelvic organ support and PFM stiffness measured after the run. Our secondary hypothesis was that, among female runners with RI-SUI, higher pelvic floor loading would be associated with more urine leakage during the run.

6.3 Methods

6.3.1 Design

This was an observational, cross-sectional exploratory study. Our local institutional research ethics board approved the protocol prior to recruitment, which occurred between June 2019 and March 2021, with a break between March 2020 and January 2021 due to laboratory closures caused by the COVID-19 pandemic. Prior to participating in any part of the protocol, all participants provided written informed consent.

6.3.2 Participants

Experienced runners were recruited through local running groups and physiotherapy clinics. The inclusion and exclusion criteria are presented in **TABLE 6.1**. All eligible participants provided demographic information including age, parity, obstetrical history (i.e. vaginal vs Caesarean section, use of forceps or suction) and menopausal status. They were also asked to complete the International Consultation on Incontinence - Female Lower Urinary Tract Symptoms Long Form module (ICIQ-FLUTS), the International Physical Activity Questionnaire (IPAQ) (Hagströmer et al., 2006), and to provide general information about their running profile such as frequency, volume, and experience. Due to the novel nature of this study, there were no prior data available to inform a sample size estimate. Consequently, the sample size was determined based on practical considerations and the availability of resources; with

assumptions that a sample size > 25 would be adequate to detect moderate linear associations (Jenkins & Quintana-Ascencio, 2020).

Table 6.1 Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
• Runners assigned female at birth • Older than 18 years old • Run at least 10 km / week for the past year • Run at least twice per week for the past year • Can run at least 5 km in under 50 minutes	• Risk factors for physical activity according to Par-Q • Self-reported obesity or obesity defined by a BMI larger than 35kg/m² • History of urogenital surgery and/or use of incontinence medication • Neurological impairments involving the central nervous system or the sacral nerves • Known connective tissue disorders • Pelvic organ prolapse that moves caudally past the hymen on Valsalva maneuver while standing • Pregnant or had delivered a baby within the previous year • Dyspareunia or pelvic pain • Symptoms of low energy deficiency as measured by the Low Energy Availability in Females Questionnaire (LEAF-Q) • <i>In situ</i> devices that would not be suitable for ultrasound imaging, intravaginal dynamometry, and/or intravaginal pressure sensor placement • Urinary urgency with associated urine leakage during running

6.3.3 Laboratory assessment

The first author, who is a registered physiotherapist who has worked exclusively in pelvic health, having over 5 years of experience at the time of data collection, conducted all laboratory assessment data. Additionally, she received over 50 hours of training on ultrasound imaging (USI) and intravaginal dynamometry to assess pelvic morphometry and PFM function prior to initiating this study and was trained on and deemed competent by the device developers on the correct use of the pressure sensor.

Further details on the procedures used in this study can be found in a previous publication (Bérubé & McLean, 2024). In brief, bladder volume was confirmed using transabdominal USI to be between 100 and 200mL to ensure consistency among participants during the running protocol. This decision was made to assess urine leakage during exercise with a moderately full bladder since female runners tend to void their bladder prior to going for a run and even during the run as a mitigation strategy to prevent leakage (Brennand et al., 2018). Before running, the morphometry of the PFMs was assessed using 2D and 3D B-mode transperineal USI through a GE Voluson S6 system (General Electric, Toronto, Canada). While in a standardized standing position, static 3D volumes (to measure the area of the levator hiatus) and dynamic 2D clips (to measure levator plate length and bladder neck height) were obtained at rest and during maximum effort voluntary contractions (MVCs). Also, in standing, an intravaginal dynamometer was used to measure MVC forces. The arms were opened to an anteroposterior diameter of 35 mm and the participant was instructed to perform an MVC. The participant then moved to a supine position and the dynamometer was used to record passive forces as the diameter of the dynamometer arms moved at a constant 50 mm/s from 15 mm to 40 mm diameter. The elongation was held for 7 seconds before the arms returned to their initial position. Three sequential repetitions of each task were performed using each device.

The dependent variables were selected as those previously shown to be impacted by an acute bout of running among experienced female runners both with and without RI-SUI (Bérubé & McLean, 2024). Imaging outcomes included the area of the levator hiatus (LA) at rest acquired using 3D imaging in standing, and bladder neck (BN) height and levator plate (LP) length at rest acquired using 2D imaging in standing. The amount of change (Δ) in the LP length and BN height was acquired as the difference in these measures between rest and peak MVC (Dietz, 2004; McLean et al., 2016). Dynamometry outcomes included peak force and rate of force development observed during active contraction in standing and passive PFM

elongation in supine (Bérubé et al., 2018; Czyrnyj et al., 2021). The relevance of each outcome is presented in Box 1.

The participants proceeded to insert a validated (Coleman et al., 2012; Hsu et al., 2012; Rosenbluth et al., 2010), reliable (Egger et al., 2015), sterilized, and calibrated (0 to 350 cm H₂O) pressure sensor into the posterior fornix of their vagina, which was zeroed to atmospheric pressure. Adequate positioning of the device was confirmed by the physiotherapist using digital palpation in the supine position by palpating the cervix and ensuring that the sensor was inserted posterior to it and as far as possible. The participants were then instructed to redress in their underwear and in standardised Spandex running pants provided by the laboratory, which held the wires still while running. Posterior fornix sensor pressure (PFSP) data were acquired at a sampling rate of 40Hz and stored on a Secure Digital card within an instrumented module that was secured to the participant's left iliac crest with adhesive tape. To ensure that the sensor was securely positioned in the upper third of the vagina, the participants were instructed to stand up and perform three maximal effort coughs, three maximal Valsalva maneuvers (MVM), three vertical jumps, and three repetitions of a standardized lifting task with 6.8 kilograms in each hand. On visual inspection, if the sensor descended into the lower part of the vagina or came out, it was reinserted, and the process was repeated. If the sensor still descended, it was removed, and the participant continued the study without the sensor. A tri-axial accelerometer (*MetaMotionR*, *Mbientlab Inc.*) with a range of $\pm 16G$ was adhered using tape directly to the skin over the upper border of the left mid-iliac crest and was used to record pelvis acceleration values in the vertical, anteroposterior and mediolateral directions at a sampling rate of 100 Hz.

With a pre-weighed incontinence pad in their underwear, and a Fit-bit watch on their wrist, participants proceeded to a NordicTrack Commercial 2450 treadmill. They gradually increased the belt speed to 7 km/h, jogged for 2 minutes, then increased the speed to 10 km/h, ran for 2 minutes, then increased the speed to 15 km/h, ran for 2 minutes then selected a

running speed that they perceived as somewhat hard (15-16 on the Borg Rate of Perceived Exertion Scale) and maintained it for 30 minutes, after which they decreased the treadmill speed to 10 km/h and then 7 km/h, running for 30s at each speed, at which point they reduced the speed to zero to end the protocol. Throughout the entire protocol, the instrumentation module recorded pressure data. If the participants experienced shortness of breath or discomfort during the running task, they had the option to reduce their speed or, if necessary, walk for one minute before resuming their selected speed. Drinking water during the running protocol was permitted. Following completion of the running protocol, the physiotherapist examined the positioning of the pressure sensor, determining whether it remained within the posterior fornix of the vagina before removing it. The USI and intravaginal dynamometry procedures were then repeated as described above, completed within 15 minutes of the end of the running protocol. Pad weight and total number of steps taken during the run were recorded. The researcher who conducted the laboratory assessment was not blinded to continence status as she could visually detect urine in the pad on removal for weighing.

6.3.4 Data processing

The change in PFM outcomes was calculated as the difference between the post-run measurements and the pre-run measurements.

All PFSP data processing was performed using custom MATLAB programs and followed methods previously established by the developers of the device (Hamad et al., 2013). Following a power spectrum analysis, no filtering was deemed necessary to smooth the pressure data as there was no evidence of high frequency noise. Maxima and minima in the pressure data were identified using custom software, with successive peaks being at least 0.2 seconds apart. Confirmation via visual inspection ensured that pressure peaks were identified correctly. Four separate measures were derived from the PFSP data to quantify pelvic floor load exposure: (i)

the difference between the mean of all maxima and of all minima was used to compute the “net mean peak PFSP” during the 30-minute run at the self-selected speed (Hamad et al., 2013), (ii) net mean peak PFSP calculated over the highest data point acquired during the three vertical jumps (Dietze-Hermosa et al., 2020) and it was used to normalize the net mean peak PFSP during running, producing the “relative net mean peak PFSP”. This measure, presented as a percentage, was used to allow meaningful comparisons among individuals considering variations in body mass and the mass of the abdominal/pelvic organs, and finally, (iii) the area under the PFSP curve (PFSP AUC) was averaged over 10 minutes of running at the self selected speed to represent cumulative loading (Hamad et al., 2013). While these measures were not independent (net mean PFSP vs relative net mean PFSP $r=0.777$; net mean PFSP vs PFSP AUC $r=0.879$, PFSP AUC vs relative net mean PFSP $r=0.635$), they were each selected as they provide different information about pelvic floor loading.

The raw pelvic acceleration time series were smoothed using a second order dual-pass Butterworth filter with a 6 Hz cut-off. Vector accelerations [vertical (y), sagittal (x) and coronal (z)] were computed over 10 consecutive steps at the self-selected speed within the 15 minute mark of the 30 minute run, using the peak acceleration values from each step (Equation 6.1), where a_x (sagittal), a_y (vertical), and a_z (coronal), represent acceleration amplitudes in the x, y, z directions, respectively, and $|\vec{a}|$ represents the vector acceleration. Again, while not independent ($r=0.693$), both vector and vertical accelerations provide different information and were thus both included in the statistical analyses.

$$|\vec{a}| = \sqrt{a_x^2 + a_y^2 + a_z^2}. \quad \text{Equation 6.1}$$

6.3.5 Statistical Analysis

All statistical testing was carried out using IBM SPSS version 28 and $\alpha=0.05$ was used for all tests. All outcomes were tested for normality using the Shapiro-Wilk test. Descriptive statistics (mean, standard deviation) were calculated for each outcome. Confidence intervals were calculated for the mean difference in PFM outcomes to describe the acute effects of the run. To test the primary hypothesis, separate linear regression analyses were conducted to evaluate the relationships between pelvic floor loading variables (net mean PFSP, relative net mean PFSP, PFSP AUC, vector acceleration and vertical acceleration) recorded during the run and changes in pelvic morphometry and PFM function after the run. The baseline value of each PFM morphometry or function outcome was included in its respective models as a covariate, since it was previously shown that baseline value BN height and LP length can affect the extent of changes observed after a run (Bérubé & McLean, 2024). To assess our secondary objective, among female runners with RI-SUI, linear regression analyses were conducted to evaluate the relationship between each of the variables representing pelvic floor loading and pad weight gain after the running protocol. Residual plots were examined to ensure proper model fit.

6.4 Results

6.4.1 Sample Demographic Information

Thirty-nine female runners met the eligibility criteria. However, only 38 successfully completed the laboratory-based assessment due to hardware issues with the dynamometer. Hardware difficulties due to faulty connections were encountered with the vaginal pressure sensor for another five participants. PFPS data were discarded for six participants due to the sensor having descended from the posterior fornix during the running task. Ultimately, PFSP data sets were available from 27 participants.

Demographic data are presented in **TABLE 6.2**. Baseline values, post-run values and mean differences in all PFM outcomes are summarized in **TABLE 6.3**. The LH was significantly

larger, and the BN was significantly lower within the pelvis in standing at rest after the run. Runners were also able to shorten their LP further when performing an MVC after the run. The PFSP and pelvic acceleration data measured during the 30-minute self-selected running speed are detailed in **TABLE 6.4**. The equations derived from the regression analyses are presented in **Supplemental material S.6.1** While most models were non-significant, as described below, the residual plots confirmed that all models met the necessary criteria for adequate model fit

Table 6.2 Demographic data for the whole sample (n=38) and for participants in whom posterior fornix sensor pressure data were available for regression analysis (n=27).

	All participants (n=38)		PFPS subset (n=27)	
	Mean/n	SD or %	Mean/n	SD or %
Age (years)	39.91	10.12	40.74	11.13
BMI (kg/m ²)	23.03	3.99	23.25	3.68
Waist to hip ratio	0.79	0.07	0.79	0.08
Parous	17	45	11	41
Use of forceps (n, %)	4	11	3	11
Use of suction (n, %)	3	8	1	4
Menopause (n, %)	4	11	4	15
RI-SUI (n, %)	19	50	15	56
ICIQ-FLUTS total score (/48)	7.37	4.56	8.07	4.50
ICIQ-FLUTS F (/16)	2.89	2.13	3.33	2.04
ICIQ-FLUTS V (/12)	0.79	1.70	0.67	1.14
ICIQ-FLUTS I (/20)	3.68	3.02	4.07	3.15
IPAQ total activity (MET-minutes/week)	4389	5951	5531	6739
IPAQ sub total vigorous activities (MET-minutes/week)	1503	2268	1819	2616.
Self-selected running speed (km/h)	10.30	1.64	10.16	1.77
Number of steps during running protocol	6489	384	6408	307
Weekly running distance (km)	36.2	23.6	36.1	23.0
Running experience (years)	15.70	10.54	15.49	11.17

Values are presented as mean $\pm$ standard deviation (SD) or the frequency and percentage (%).

PFSP: posterior fornix sensor pressure; BMI: body mass index; RI-SUI: running-induced stress urinary incontinence; ICIQ-FLUTS: International Consultation on Incontinence - Female Lower Urinary Tract Symptoms Long Form module; F: filling subscore; V: voiding subscore; I: Incontinence subscore, IPAQ: International Physical Activity Questionnaire; MET: metabolic equivalent units

Table 6.3 Baseline outcomes and post-run changes measured by intravaginal dynamometry and ultrasound imaging

	Before the run		After the run		Difference (Δ)				
	Mean	SD	Mean	SD	Mean	SD	95% CI		n
Dynamometry outcomes during MVC									
Rate of force development (N/s)	9.45	6.08	9.45	6.72	0.00	2.70	-1.024	1.033	28
Relative peak force (N)	3.64	1.51	3.91	1.68	0.27	0.86	-0.054	0.602	28
Dynamometry outcomes during passive elongation									
Rate of force development (N/s)	30.33	11.69	28.69	10.70	-1.64	6.58	-4.137	0.865	28
Relative peak force (N)	11.38	5.16	10.88	5.73	-0.50	2.05	-1.280	0.279	28
3D USI measurements									
LH area at rest (cm2)	16.90	4.94	17.70	5.12	0.80	1.35	0.324	1.267	33
2D USI measurements at rest									
Bladder neck height (mm)	16.75	4.78	14.59	4.13	-2.16	3.29	-3.273	-1.049	35
Levator plate length (mm)	55.59	8.24	56.92	9.06	1.33	4.55	-0.187	2.848	36
2D USI measurements change on MVC									
Bladder neck height (mm)	3.36	3.56	4.01	2.94	0.66	2.55	-0.218	1.532	34
Levator plate length (mm)	-10.38	4.64	-11.89	5.59	-1.51	4.07	-2.890	0.133	35

Confidence intervals significantly different from zero are shown in bold.

MVC: maximal voluntary contraction; 2D: 2 dimensional; 3D: 3 dimensional; US: ultrasound imaging; N: Newtons; N/s: Newtons per second; mm: millimeters; SD: standard deviation; n=sample size; Δ : absolute difference; CI: confidence interval

Table 6.4 Pelvic floor loading outcomes measured using intravaginal posterior fornix sensor and pelvic accelerometers during running for 30-minutes at a self-selected speed

	n	Mean	SD	Range	CoV (%)
Net mean peak PFSP (cm H2O)	27	43.84	13.21	17.66-77.42	30.1
Relative net mean peak PFSP (%)	27	57.72	22.00	27.80-99.80	38.1
AUC PFSP (cm H2O·s)	27	177.10	37.22	114.69-255.66	21.0
Vertical acceleration (g)	38	2.62	0.28	2.06-3.26	10.2
Vector acceleration (g)	38	3.52	0.40	2.75-4.24	11.7

PFSP: posterior fornix sensor pressure; cm H2O: centimeters of water; AUC: area under the curve; g: gravitational unit; SD: standard deviation; s: second; CoV: coefficient of variation

Table 6.5 Regression coefficients and confidence intervals for the relationships between pelvic floor loading (posterior fornix sensor pressure and pelvic accelerations) and change in pelvic floor muscle function outcomes.

	Net mean PFSP				Relative net mean PFSP				AUC PFSP				Vertical acceleration				Vector acceleration			
	R2	B	95% CI		R2	B	95% CI		R2	B	95 % CI		R2	B	95% CI		R2	B	95% CI	
Dynamometry outcomes during MVC																				
Rate of force development	0.01	0.026	-0.128	0.180	0.02	0.016	-0.067	0.099	0.008	0.002	-0.045	0.050	0.00	0.071	-4.083	4.225	0.081	1.985	-0.72	4.690
Relative peak force	0.10	-0.019	-0.064	0.026	0.07	0.005	-0.018	0.029	0.118	-0.007	-0.021	0.007	0.01	-0.028	-1.348	1.292	0.094	0.683	-0.205	1.571
Dynamometry outcomes during passive elongation																				
Rate of force development	0.17	-0.104	-0.498	0.291	0.19	-0.077	-0.268	0.115	0.175	0.035	-0.083	0.154	0.26	-7.141	-15.913	1.631	0.27	-5.187	-11.181	0.807
Relative peak force	0.20	-0.098	-0.217	0.020	0.18	-0.046	-0.107	0.015	0.048	0.004	-0.036	0.045	0.20	-3.399	-6.228	-0.569	0.273	-2.747	-4.585	-0.908
3D US measurements																				
LH area at Rest	0.12	-0.022	-0.066	0.022	0.12	-0.014	-0.042	0.013	0.082	-0.003	-0.019	0.013	0.01	-0.347	-2.233	1.538	0.037	-0.635	-1.825	0.555
2D US measurements at rest																				
Bladder neck height	0.21	0.046	-0.035	0.128	0.48	0.020	-0.027	0.067	0.491	0.016	-0.014	0.045	0.30	-1.455	-5.151	2.241	0.281	-0.130	-2.750	2.490
Levator plate length	0.03	0.096	-0.076	0.267	0.11	0.054	-0.043	0.151	0.088	0.026	-0.034	0.087	0.08	4.538	-1.105	10.181	0.012	-0.804	-4.749	3.141
2D US measurements change on MVC																				
Bladder neck height	0.35	0.000	-0.082	0.082	0.35	-0.003	-0.050	0.043	0.35	-0.001	-0.03	0.028	0.34	0.867	-1.873	3.607	0.352	0.841	-1.054	2.736
Levator plate length	0.16	-0.095	-0.253	0.063	0.16	-0.055	-0.143	0.033	0.132	-0.025	-0.08	0.031	0.06	-2.377	-7.889	3.136	0.058	1.797	-2.089	5.684

PFSP: posterior fornix sensor pressure; MVC: maximal voluntary contraction; 2D: 2 dimensional; 3D: 3 dimensional; LH: levator hiatus; USI: ultrasound imaging; n=sample size; AUC: area under the curve; B: beta coefficient of the regression for the PFSP or pelvic accelerations; CI: confidence interval, R2: coefficient of determination

6.4.2 Relationship between changes in pelvic floor loading exposure during running and changes in pelvic morphometry and PFM function after the run

The outcomes of the linear regression analyses are presented in **TABLE 6.5**. The only regression models that were significant were the amount of change in relative peak passive force observed on PFM elongation and pelvic accelerations (both vertical and vector) observed during running. **FIGURES 6.1 & 6.2** present scatterplots showing the relationships between pelvic floor loading exposure (net mean PFSP and pelvic vertical accelerations) and both dynamometry and USI outcomes, respectively. The outcome of the regression analyses is described in more detail below.

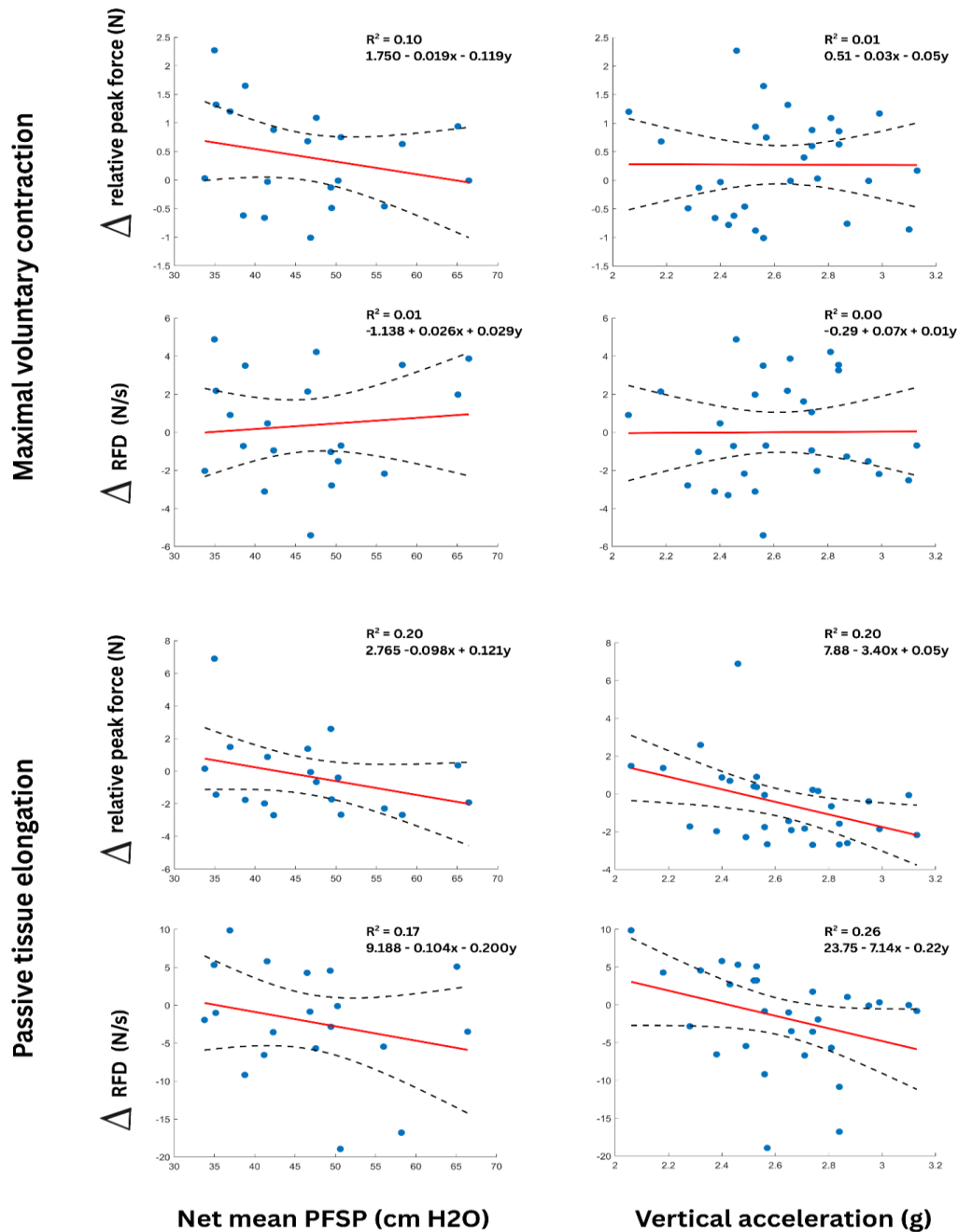


Figure 6.1 Scatterplots of the change in relative peak force and RFD during MVC (4 upper panels) and during passive tissue elongation (4 lower panels) after the run in relationship with pelvic floor loading (Left: net mean PFSP; right: vertical accelerations) measured during the run. The regression lines and their 95% confidence intervals are depicted. The equations are in the form $B_0 + B_1x + B_2y$, where B_0 is the intercept, B_1 is the coefficient associated with the measure of pelvic floor loading and B_2 is the coefficient associated with the baseline value of the pelvic floor muscle outcome indicated. PFSP: posterior fornix sensor pressure; RFD: rate of force development; MVC: maximal voluntary contraction, Δ : change; N: Newtons; N/s: Newtons per second; g: gravitational unit, R^2 : coefficient of determination.

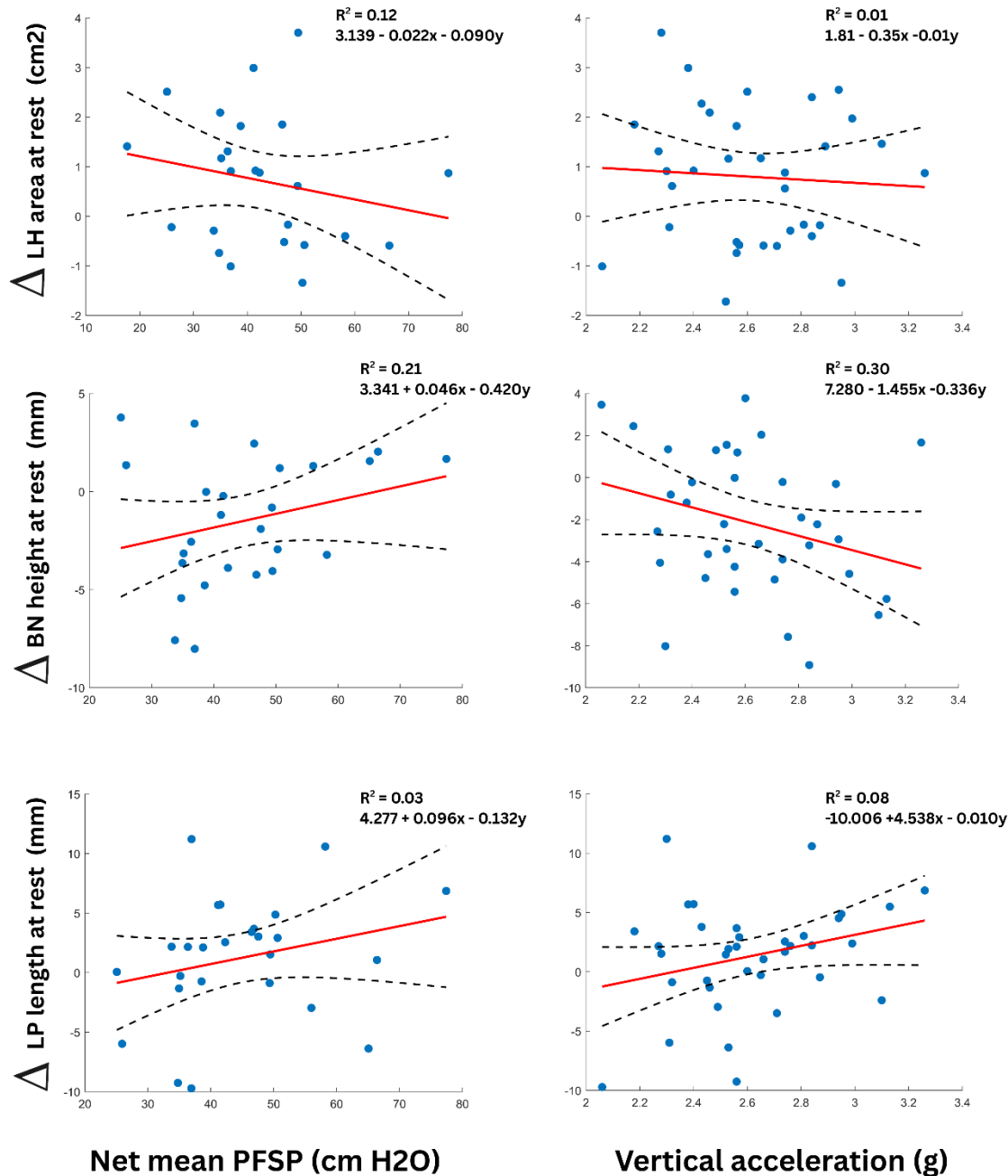


Figure 6.2 Scatterplots of the change in levator hiatus (LH) area at rest, bladder neck (BN) at rest and levator plate (LP) length after the run in relationship with pelvic floor loading (Left: net mean PFSP; right: vertical accelerations) measured during the run. The regression lines and their 95% confidence intervals are depicted. The equations are in the form $B_0 + B_1x + B_2y$, where B_0 is the intercept, B_1 is the coefficient associated with the measure of pelvic floor loading and B_2 is the coefficient associated with the baseline value of the pelvic floor muscle outcome indicated. PFSP: posterior fornix sensor pressure; Δ : change

6.4.2.1 Dynamometry outcomes

Contractile forces

There was no difference in MVC force or rate of force development after the run compared to before the run. The extent of pelvic loading (PFSP, pelvic accelerations) exposure during running did not affect the magnitude or rate of force generated during PFM MVC. The regression models suggest that pelvic floor loading during the run explains little to none of the variance (1% to 12%) in the change in contractile force observed after the run.

Passive tissue elongation

As noted above, exposure to higher pelvic accelerations, both vertical and vector, was associated with reduced rate of force development during passive elongation of the PFMs after the run (i.e., stiffness) and with peak passive resistance (Figure 1) after the run, with models explaining between 20 and 27% of the variance in the data. Pelvic floor loading exposure, when measured through PFSP (net mean PFSP, relative net mean peak PFSP, and AUC PFSP) was not associated with changes in pelvic floor tissue stiffness measured using vaginal dynamometry after the run, with models explaining between 5 to 20% of the variance (Figure 5.1).

6.4.2.2 Ultrasound imaging outcomes

Levator hiatus

While LH area was larger when measured in standing at rest after the run, the magnitude of pelvic floor loading exposure (measured through both PFSP and pelvic accelerations) was not associated with the extent of observed changes after the run. The models explained between 8 and 12% of the variance in PFSP and between 1 and 4% of the variance in pelvic accelerations.

Bladder neck height

Bladder neck height was lower when measured in standing at rest after the run compared to before the run. Pelvic accelerations explained between 28 and 30% of the variance in the

change in BN height at rest after the run (Figure 2). During the MVC, there was more elevation of the BN after the run. For the PFSP variables, the regression models explained between 21 to 49% of the variance in the data, however the significant predictor in these models was the BN height before the run, not the loading exposure during the run. Runners who initially had a more cranial BN position before the run were more likely to experience greater caudal shifts in BN position afterward, both at rest and on MVC.

Levator plate length

The LP was not significantly longer after the run. Neither pelvic accelerations nor PFSP had a meaningful impact on the resting length of the LP, nor its ability to shorten on MVC after the run compared to baseline. The regression models explained between 3 and 16% of the variance in the data.

6.4.3 Relationship between pelvic floor loading and pad weight gain among runners with RI-SUI

Among the runners with RI-SUI, PFSP (net mean PFSP, relative net mean PFSP, AUC PFSP) explained little to no variance in pad weight gain ($n=15$, $R^2=0.039$, 95% CI [-1.415 0.703], slope=-0.356, $p=0.481$; $R^2=0.000$, 95% CI [-0.726 0.677], slope=-0.025, $p=0.941$; $R^2=0.048$, 95% CI [-0.597 0.271], slope=-0.163, $p=0.432$, respectively). While similar results were obtained for vertical accelerations ($R^2=0.015$, 95% CI [-92.952 56.604], slope= -18.174, $p=0.615$), slower vector accelerations were associated with greater pad weight gain after the run ($R^2=0.273$, 95% CI [-100.193 -9.053], slope= -54.623, $p=0.022$) ($n=19$).

6.4.4 Sensor dislodgement

Five out of the 6 participants in whom the sensor dislodged were parous. We compared pelvic floor morphometry and dynamometry between the parous runners in whom the sensor became dislodged and those in whom the sensor remained within the posterior fornix (APPENDIX 2). There were no significant between-group differences but the LH and LP of the

parous runners who lost the sensor tended to be larger and longer, there was less tissue stiffness during passive elongation of the paravaginal tissues and PFM force-generating capacity was lower.

6.5 Discussion

To our knowledge, this is the first study to explore the direct relationship between pelvic floor loading during a single exercise session and transient changes in pelvic floor morphometry and function observed afterward. The results provide some evidence that pelvic floor loading, particularly when inferred through pelvic accelerations, may contribute to stress relaxation of the pelvic supporting tissues in female runners. The effects were, however, not consistent across all measures. The observations using intravaginal dynamometry suggest that faster pelvic accelerations during running, thus higher ground reaction forces (Patoz et al., 2022), cause the connective tissues within and/or anchoring the PFMs to become less stiff, without negatively influencing their contractile function. However, the area of the LH and the LP length at rest, as measured by USI, were not affected by the magnitude of the pelvic accelerations, suggesting that tissue changes were related to stress relaxation and not to creep. There was also no evidence that higher pressures measured within the posterior fornix during running were associated with greater changes in bladder neck support or PFM function over the course of the run. While there is evidence of tissue strain after the run (lower BN height, larger LH area) the extent of tissue strain does not appear to be associated with the magnitude of the loading forces experienced during the run. As such, our primary hypothesis was not supported.

Furthermore, our secondary hypothesis was not supported as higher exposure of the pelvic floor to loading was also not associated with greater pad weight gain among those with RI-SUI. Interestingly, there was an inverse relationship between pad weight gain during running and pelvic vector accelerations while running. The underlying mechanisms for this observation remain unclear, runners with RI-SUI might have adopted running mechanics that reduce vector

acceleration to mitigate leakage or running with a soaked incontinence pad may have affected their running mechanics (Brennand et al., 2018). While minimizing pelvic accelerations could offer a strategy to mitigate the extent of pelvic floor stress relaxation experienced during running, this might not impact leakage symptom severity. A case study demonstrated that instructing a participant to reduce vertical loading by running “more softly” led to a reduction in tibial acceleration, vertical oscillation of her center of mass, and, ultimately, a reduction in symptoms of urine leakage during running (Steimling et al., 2023). Increasing cadence/decreasing stride length, improving shock absorption through stronger lower limb muscles or appropriate footwear, and/or reducing running speed, among other biomechanical interventions could reduce pelvic loading (Davis et al., 2020; Folland et al., 2017; Moore, 2016). Further research is necessary to evaluate the effectiveness of biomechanical strategies for mitigating pelvic floor loading and associated reductions in urine leakage.

Bladder neck height at rest and its elevation on MVC prior to the run significantly influenced BN height in standing and change of position in BN height attained on MVC after the run, while the extent of pelvic floor loading (peak PFSP and pelvic accelerations) did not. A higher BN position before running appears to allow for more descent of the BN during the run. A potential explanation could be that a lower BN at rest might indicate that the supportive structures of the BN are already in an elongated position prior to the run, thus the tissues may be closer to their maximum strain, leaving them less room for descent compared to those whose BN is located higher in the pelvis before the run (Bérubé & McLean, 2024).

Middlekauf et al. reported no differences in maximal vaginal descent, vaginal resting pressure and maximal and mean PFM strength (Middlekauff et al., 2016) between a group of nulliparous females who completed a strenuous exercise protocol and those who completed a nonstrenuous (walking) exercise protocol. Assuming that the participants who completed the strenuous protocol experienced higher loads on their pelvic floor compared to the nonstrenuous protocol, their finding is consistent with the results of the current study; both suggest that the

magnitude of peak or cumulative loading during exercise is not strongly associated with changes in PFM structure or function that occur due to the exercise. Indeed, previous research has demonstrated that approximately 50% of the variability in urethral mobility among females can be attributed to genetic factors (Dietz et al., 2005) thus it is quite possible that intrinsic factors such as genetics may predispose some runners to greater loss of BN support than others, regardless of pelvic loading exposure during running. Our results and those of Middlekauff et al. (Middlekauff et al., 2016) suggest that intrinsic contributors to the loss of pelvic organ support during running should be investigated in future work.

6.5.1 Measurement of pelvic floor loading

Both the vertical component of pelvic accelerations and the overall vector accelerations were associated with reduced stiffness in the PFMs observed after the run. While pelvic accelerations are highly correlated with ground reaction forces (Patoz et al., 2022), it is not yet known how ground reaction forces are transmitted to the pelvic floor. Similar to the findings of this study, a recent study found no association between running kinetics or pelvic accelerations and symptoms of pelvic floor dysfunction in a sample of postpartum runners (Coltman et al., 2025).

The pelvic floor is a multiplanar network of soft tissues that is subjected to loading through the vertical oscillations of the abdominal and pelvic contents. Intravaginal accelerometry may offer a direct means of measuring pelvic floor kinematics to improve our understanding of pelvic floor loading (Niederauer, Bérubé, et al., 2022). It appears that a history of vaginal childbirth may impact the capacity of the pelvic floor tissues to dampen pelvic floor oscillations (Niederauer, Bérubé, et al., 2022). Further investigation is warranted to understand not just the magnitude of loads to which the pelvic floor is exposed, but the response of the pelvic floor to those loads.

While the pressure sensor used in this work has been validated as an indirect means of measuring IAP during activities (Coleman, Hamad, et al., 2015; Coleman, Nygaard, et al., 2015; de Gennaro et al., 2019; Hsu et al., 2017; Shaw et al., 2014), when worn during physical activities

performed in an upright position, pressure measured by a sensor placed in the posterior fornix of the vagina measures the summed forces acting to compress the sensor. Gravitational loading from the abdominal/pelvic contents and inertial loading from reaction forces likely contribute the majority of the compressive forces acting on the sensor during high impact activities. A previous study found a strong positive correlation between net mean peak PFSP and pelvic accelerations during walking ($r=0.7220$) (de Gennaro et al., 2019). In contrast, weaker correlations were observed during running ($r=0.347$) (Bérubé et al., 2024), further demonstrating that inertial loading appears to influence the PFSP. The signal processing methods used here removed any offset related to static gravitational loading and reflected loads during running that were between 27.8 and 99.8% of the pressure recorded during a vertical jump. While previous studies have referred to this pressure as IAP, we chose the more accurate term of PFSP to encompass the multidirectional and summative forces acting on the sensor, which largely represents loads experienced by the pelvic floor. The results of this study suggest that pelvic floor loading measured through PFSP is not associated with the extent of strain observed in the pelvic organ support structures after the run and is not associated with the amount of urine leaked.

6.5.2 Limitations and next steps

As our sample lacked diversity, the findings of this research are representative of White, experienced runners. They are also specific to treadmill running and may not be translatable to other types of high-impact activities. Due to the exploratory nature of this study, we investigated several outcomes and did not use alpha adjustments to account for the multiple outcomes, which may be considered a limitation. Indeed, alpha correction is not required when outcomes are independent (Rubin, 2021), however the five measures used to infer pelvic floor loading were dependent. We chose to include all measures as they each represent different contexts of pelvic floor loading and thus had the capacity to inform on different aspects of the biomechanical influences on the tissues. There was large variance in the PFSP data, which may have influenced

our ability to detect meaningful relationships between PFSP and pelvic morphometry and PFM function.

Ideally a multivariable regression analysis would be used, however, due to the small sample size, the regression models were limited to two independent variables. However, other factors such as continence status, BMI, parity, age, running mechanics, and weekly running distance may also contribute to the influence of pelvic floor loading on pelvic morphometry and PFM function. Adding these potential confounders would require a six-fold increase in the sample size, which was not feasible for this exploratory study. Future studies should explore the influence of these characteristics on running-induced changes in pelvic morphometry and PFM function.

Hardware issues with IAP sensor (n=5) and sensor dislodgement (n=6) contributed to us having substantive data loss for the PFSP measures. Changes in pelvic floor morphometry induced by vaginal birth was likely the primary reason for this. While this same sensor has been widely used during dynamic physical activity performed by parous females, in this study, we measured PFSP over a longer bout of exercise, which might explain why dislodging of the sensor has not previously been reported as a problem. In future work, use of a sensor that is better able to be retained within the posterior fornix, or perhaps device located in the stomach or rectum, would provide more robust data.

Previous research has shown that compressive shorts can provide pelvic organ support and relieve SUI (Okayama et al., 2019) and as such, we opted to standardize the pants that the participants wore during running. These pants did not provide substantive abdominopelvic compression, however, the vaginal sensor itself and the lycra pants could have interfered with study outcomes.

Based on the outcomes of this study, there remains limited evidence to support advising females with athletic incontinence to refrain from running as a form of exercise, or to change their running mechanics to reduce pelvic floor loading. Such advice could lead to kinesiphobic

behaviors, which may, in turn, result in adverse health consequences associated with inactivity. Urinary symptoms themselves are a significant barrier to regular, sustained, and intense exercise (Brennand et al., 2018). This can, in turn, contribute to decreased physical fitness and overall well being (Brennand et al., 2018). Much work is still needed before biomechanical interventions should be recommended. Future studies should aim to incorporate robust biomechanical data with tools to assess pelvic floor morphometry and function to better understand how different movement patterns or loading conditions impact female pelvic health. Longitudinal studies are also needed to assess the long-term impact of loading on the pelvic floor. Additionally, further research is still needed to explore how conservative management strategies could benefit individuals with athletic incontinence.

6.6 Conclusion

Although no significant correlations were found between pelvic loading exposure during a run and changes in PFM contractile strength after the run, higher pelvic skeletal accelerations were associated with greater loss in passive stiffness of the paravaginal tissues after the run. Intrinsic factors may influence reductions in pelvic organ support induced by loading exposure and should be investigated.

6.7 Supplemental material

Table 6.6 Linear regression equations for pelvic floor muscle morphometry and function outcomes based on pelvic floor loading (PFSP or pelvic accelerations) exposure during the run. The equations are in the form $B_0 + B_1x + B_2y$, where B_0 is the intercept, B_1 is the coefficient associated with the measure of pelvic floor loading indicated in the column header and B_2 is the coefficient associated with the baseline value of the pelvic floor muscle outcome indicated in the row header.

	Net mean PFSP	Relative net mean PFSP	AUC PFSP	Vertical acceleration	Vector acceleration
Dynamometry outcomes during MVC					
Rate of force development	$-1.138 + 0.026x + 0.029y$	$-0.770 + 0.016x + 0.013y$	$-0.457 + 0.002x + 0.035y$	$-0.29 + 0.07x + 0.01y$	$-7.23 + 1.98x + 0.02y$
Relative peak force	$1.750 - 0.019x - 0.119y$	$0.700 + 0.005x - 0.164y$	$2.180 - 0.007x - 0.133y$	$0.51 - 0.03x - 0.05y$	$-2.15 + 0.68x + 0.00y$
Dynamometry outcomes during passive elongation					
Rate of force development	$9.188 - 0.104x - 0.200y$	$9.604 - 0.077x - 0.212y$	$-1.667 + 0.035x - 0.217y$	$23.75 - 7.14x - 0.22y$	$23.13 - 5.19x - 0.21y$
Relative peak force	$2.765 - 0.098x + 0.121y$	$1.384 - 0.046x + 0.099y$	$-2.253 + 0.004x + 0.093y$	$7.88 - 3.40x + 0.05y$	$8.68 - 2.75x + 0.05y$
3D USI measurements					
Levator hiatus area at rest	$3.139 - 0.022x - 0.090y$	$2.905 - 0.014x - 0.084y$	$2.657 - 0.003x - 0.088y$	$1.81 - 0.35x - 0.01y$	$3.15 - 0.63x - 0.01y$
2D USI measurements at rest					
Bladder neck height	$3.341 + 0.046x - 0.420y$	$4.280 + 0.020x - 0.423y$	$2.394 + 0.016x - 0.406y$	$7.280 - 1.455x - 0.336y$	$4.344 - 0.130x - 0.361y$
Levator plate length	$4.277 + 0.096x - 0.132y$	$5.935 + 0.054x - 0.142y$	$3.963 + 0.026x - 0.135y$	$-10.006 + 4.538x - 0.010y$	$6.880 - 0.804x - 0.049x$
2D USI measurements change on MVC					
Bladder neck height	$2.046 + 0.000x - 0.427y$	$2.237 - 0.003x - 0.422y$	$2.232 - 0.001x - 0.426y$	$-0.296 + 0.867x - 0.393y$	$-1.003 + 0.841x - 0.392y$
Levator plate length	$-0.190 - 0.095x - 0.256y$	$-1.223 - 0.055x - 0.256y$	$-0.460 - 0.025x - 0.296y$	$3.693 - 2.377x - 0.097y$	$-10.017 + 1.797x - 0.214y$

Coefficients that were significantly different from zero are indicated in red.

PFSP: posterior fornix sensor pressure; MVC: maximal voluntary contraction; 2D: 2 dimensional; 3D: 3 dimensional; USI: ultrasound imaging; AUC: area under the curve.

Table 6.7 Comparison of mean (standard deviation) pelvic floor outcomes and pelvic accelerations between parous runners with and without posterior fornix sensor displacement and corresponding one-way p-value.

	Parous runners (n=16)				p-value
	Sensor remained (n=11)		Sensor dislodged (n=5)		
	Mean	SD	Mean	SD	
Dynamometry outcomes during MVC					
Rate of force development (N/s)	9.62	4.09	7.27	4.46	0.318
Relative peak force (N)	3.59	1.20	3.43	1.91	0.834
Dynamometry outcomes during passive elongation					
Rate of force development (N/s)	25.43	8.45	22.13	6.44	0.459
Relative peak force (N)	9.14	2.16	7.87	1.37	0.256
3D USI measurements					
LH area at rest (cm2)	18.99	4.45	23.34	4.24	0.087
2D USI measurements at rest					
Bladder neck height (mm)	15.18	6.25	16.27	5.03	0.760
Levator plate length (mm)	58.36	7.55	64.15	3.04	0.125
Accelerations					
Vertical (g)	2.49	0.26	2.66	0.24	0.235
Vector (g)	3.48	0.37	3.48	0.53	0.976

MVC: maximal voluntary contraction; LH: levator hiatus; 2D: two-dimensional; 3D: three-dimensional; USI: ultrasound imaging; N: Newtons; N/s: Newtons per second; mm: millimeters; SD: standard deviation; n=sample size; Δ: difference

6.8 References

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Chapter 7 General Discussion

There has been increasing interest in understanding athletic incontinence due to its significant negative impact on participation in physical activities. Back when I initially proposed this thesis research in 2018, although there were many prevalence studies using self-administered questionnaires quantifying PFD in active females, only two laboratory-based studies had been published on the impact of exercise on the PF (Middlekauff et al., 2016; Ree et al., 2007), along with a narrative review that discussing the possible associations between physical activity and PFD (Nygaard & Shaw, 2016). Since then, as shown in the overview of the literature presented in Chapter 2, there has been a push toward understanding athletic incontinence.

Many female athletes experience symptoms of UI during exercise (Almoussa & Bandin Van Loon, 2019; Pires et al., 2020; Rebullido et al., 2021; Teixeira et al., 2018), particularly during running (Hamilton et al., 2023; Pires et al., 2020), which can lead to reduced confidence, decreased participation in sports, and impaired quality of life (Dakic et al., 2021; Hamilton et al., 2023). Despite its high prevalence, much remains unknown about the underlying mechanisms and factors contributing to this condition, especially in female runners.

This dissertation aimed to address these gaps in knowledge by investigating differences in pelvic organ support and PFM function between female runners with and without symptoms of RI-SUI, with an aim of identifying factors that may contribute to urinary leakage. Using a combination of novel and established techniques, we explored the baseline characteristics of the PFMs among female runners with and without RI-SUI and how an acute run affects PFM morphometry and function. In addition, we developed a protocol for measuring PF loading during running and examined its feasibility before using it to evaluate the potential relationship between PF loading during running and changes in pelvic organ support and PFM function

observed after the run. This research expands our current knowledge in this under-researched area and contributes to a broader understanding of the mechanisms underlying RI-SUI.

In the following sections, I provide a comprehensive overview of the salient findings of each study, and how they can be integrated to offer novel insights into the pathophysiology exercise incontinence experienced by female runners. I discuss the strengths and limitations of this work and share my thoughts on areas for potential improvement and alternative interpretations. Additionally, I explore the clinical implications of the results, emphasizing how they inform current practice in the management of athletic incontinence, and suggest future research directions identified through this research.

7.1 Summary of findings and their relevance

7.1.1 Differences in pelvic floor morphometry and function between runners with and without running-induced stress urinary incontinence

While a handful of studies has investigated differences in PF properties between athletes with and without symptoms of SUI (Bo et al., 1994; Campos et al., 2025; Da Roza et al., 2015; de Melo Silva et al., 2020; de Mendonça et al., 2023; Koenig et al., 2020, 2021), a comprehensive understanding of how running exposure affects pelvic organ support and PFM function is lacking.

This first objective of the thesis was addressed in the first study: to determine whether measurable differences exist in PF morphometry and function between female runners with RI-SUI and those without a history of incontinence. Our findings revealed that runners with RI-SUI exhibited less passive support, as evidenced by a significantly lower rate of force development during passive tissue elongation (i.e. less tissue stiffness), trends toward lower peak force at end elongation, a larger levator hiatus, and lower positioning of the bladder neck. Despite these

indicators of compromised passive support, we observed a significantly higher rate of force development during contraction and a trend towards greater force-generating capacity, as well as enhanced cranial movement of the bladder neck on contraction. These results suggest that runners with RI-SUI possess better PFM contractile function, but lower passive pelvic organ support compared to their continent counterparts. These findings align with a current conceptual model that suggest that impaired PFM function such as strength, may not be the main driving factor for UI in female athletes and that there might be a compensatory response to the loss of passive support (Gan & Smith, 2023). The results from Study 1 are the first to demonstrate morphological differences between runners with and without RI-SUI and point to a loss of passive support of the bladder and urethra as a contributing factor. The observed differences in PFM contractile function despite similar running experience and weekly running volume suggest that runners with leakage may compensate for diminished passive support by developing stronger contractile function in their PFMs. The trend towards greater urethral wall diameter among those with R-SUI also suggests that the striated urethral sphincter might hypertrophy along with the levator ani muscles. Urethral sphincter hypertrophy has previously been observed after 12-week of PFMT in females with SUI (McLean et al., 2013). However, the runners with leakage were recruited specifically because they leak, so if changes in PFM function are indeed compensatory, the changes observed in this sample were not sufficient to counteract the loss of passive support, particularly during the repetitive high-impact exposure induced by running.

Although better contractile function was observed in runners with RI-SUI compared to continent runners, this was not the case for all runners with RI-SUI, reinforcing a need for individual assessment to determine which deficiencies or combinations of deficiencies may require intervention.

The findings from Study 1 suggest that PF loading during running is not the only factor contributing to changes in the pelvic organ support that may be associated with urine leakage,

since both runners with and without RI-SUI had similar running exposure. There might therefore be predisposing characteristics in the tissues themselves that contribute the development of SUI among active females.

In sum, this first study established that measurable differences in PFMs characteristics do exist between runners with and without RI-SUI. The next logical step was to evaluate how these characteristics change following a single bout of running, which was the second objective of this thesis.

7.1.2 Acute effects of running on pelvic floor morphometry and function

The study aimed to examine the transient effects induced by a single running session on PF morphometry and function, comparing observed changes between female runners with and without RI-SUI. The results showed no significant changes in PFM function after a 37-minute running session in either group (runners with or without RI-SUI) as measured using intravaginal dynamometry. USI revealed significant changes in PF morphometry after running, regardless of continence status. The area and anteroposterior diameter of the levator hiatus were larger, the bladder neck height was lower, and the levator plate length was longer after the run. These changes suggest that an acute bout of running results in transient strain of the passive tissues of the PF in all runners, without concurrent changes in PFM function.

These findings, coupled with the observations from study 1, suggests that runners with RI-SUI may begin with an already compromised passive support system. While all runners experienced a similar reduction in passive support and stiffness following running, there may be a threshold beyond which there is insufficient urethral closure pressure during PF loading to prevent urinary leakage. Optimizing PF support before running may therefore mitigate urine

leakage that can develop over the course of the run. This may be a promising avenue for intervention and warrants further investigation.

While the second study was underway, a second research group published their study on the acute effects of a half-marathon on PFM function. They measured PFM strength and both static and dynamic endurance using manual assessment (PERFECT tool) and also recorded surface EMG in the perianal region during sustained contractions. Eight female runners with RI-SUI and 14 continent runners (de Mendonça et al., 2023) participated. The authors reported evidence of decreased strength and endurance in both groups after the run, suggesting that the PFMs may experience fatigue among all runners after a half marathon. Similar to our findings, they did not observe any between-group differences between runners with and without RI-SUI. They also reported no change in EMG amplitude but an increase in the median frequency of the perianal EMG signal recorded during 3 contractions among the continent runners (de Mendonça et al., 2023). The authors did not provide an explanation for this observation, as it runs counter to expectation. Normally the EMG frequency spectrum shifts to lower frequencies with fatigue. Muscle fatigue could have caused more recruitment of motor units to maintain force production and increased the EMG signal (Royer, 2005), or increased recruitment of fast-twitch muscle fibers after the run could also increase the signals recorded. It is unclear if the EMG electrodes were removed and replaced after the run or if they were kept in place and therefore, pre-post run reliability could be questioned. Also, PFM EMG recorded using superficial electrodes placed in the perianal region would predominantly reflect the EMG activity of the external anal sphincter, which is not directly associated with urinary continence control. These results should be interpreted with caution since the perianal electrodes would have measured the electrical activity of many surrounding structures (crosstalk) and this poses a threat to repeatability and validity (Rai et al., 2023; Worman et al., 2023). In Mendonca et al, PFM function was evaluated using a digital palpation technique, which is subjective and could lead to bias. It has also been shown that manual palpation may not be as sensitive to subtle

changes in rate of force development and strength compared to using intravaginal dynamometry (Morin et al., 2004) . Indeed, studies evaluating the correlation between dynamometric measurements and the Oxford scale found large overlap in dynamometric force measurements among Oxford scale grades (Morin et al., 2004) and only moderate correlations (Navarro Brazález et al., 2018). Additionally, positioning during PFM assessment has been shown to affect measures of PFM function (Huang et al., 2023). While PFM function was assessed in the standing position in our study, it was assessed in the supine position in Mendonça et al. Given that running is an upright activity that subjects the tissues to gravitational loading in the standing position, future research should aim to assess PFM function using objective measurement tools in standing, as was performed in this thesis.

The discrepancies between the Mendonca et al. results and ours could be attributed to several factors. One key difference is the duration of the run: while participants in this thesis research completed a 37-minute running protocol, the participants in de Mendonça's study ran a half-marathon resulting in an average of just over 2 hours of running (de Mendonça et al., 2023). Prolonged running might cause more urinary symptoms and may induce more pronounced changes in PFM function that were not captured in our study.

Overall, the study presented in this thesis used much stronger methodology than that of previous research. Using a combination of recommended tools to concurrently assess PF morphometry and function in a standing position allowed for a more comprehensive evaluation of how the PF responds to an acute exercise bout, enhancing the validity of the findings compared to what had been previously done using a vaginal manometer (Ree et al., 2007) or a vaginal manometer with concurrent EMG (Skaug et al., 2023) in a supine position.

Given that there were reductions in passive pelvic organ support induced by the running protocol used in this study, the next objective was to evaluate whether PF loading exposure, measured using an intravaginal pressure sensor and pelvic accelerometry, significantly impacts

PF morphometry and function following an acute bout of running. However, it was crucial to first determine the feasibility of using the intravaginal sensor for this purpose. As such, the third study in this thesis was a feasibility study.

7.1.3 Feasibility of using an intravaginal intra-abdominal pressure⁴ sensor during running and its association with running-induced stress urinary incontinence

There were several aims of this feasibility study, with a main goal of ultimately developing a methodology to investigate differences in PF loading between females with and without RI-SUI. The first objective was to determine the relationship between pelvic accelerations and PFSP during running—if pelvic accelerations are highly correlated with PFSP during running, they could be used as a less invasive proxy to assess PF loading during dynamic gait-based activities. The second objective was to investigate the impact of running speed on PF loading, while the third was to ensure that the PFSP signal is stable after a prolonged running period, without sensor dislodgement. Finally, we aimed to estimate the effect size of PF loading during running, measured using the intravaginal PFSP and pelvic accelerometry, between runners with and without RI-SUI.

While positive associations were found between pelvic acceleration and both absolute peak and normalized sensor pressure, these associations accounted for less than 20% of the variance in linear regression models. We concluded that, although it had been previously suggested that pelvic acceleration could be used to estimate PFSP during walking (de Gennaro et al., 2019), it is not a valid measure of PFSP during running. The results also showed that peak PFSP significantly increased with increasing running speed and that pressure tended to be higher in runners with RI-SUI than in continent runners, although the difference was not

⁴ For the third publication, we used intra-abdominal pressure (IAP) sensor because it is consistent with terminology used in existing literature. However, for the 4th publication, we proposed changing the term to posterior fornix sensor pressure, which more accurately reflects what the sensor measures.

statistically significant. A major observation was that PFSP was highly variable across participants and that the sensor was expelled in nearly 15% of the participants. At the same speed, some participants could experience as much as three times the PFSP as another participant with similar BMI, height, and waist to hip ratio.

Furthermore, the results of this study raised concerns about the use of an intravaginal pressure sensor to assess IAP during dynamic activities such as running. The high between-subject variability complicates the interpretation of data, making it challenging to draw generalizable conclusions about the impact of physical activities on PFSP. While intravaginal sensors may provide valuable insights into the forces transmitted to the PF, their use in clinical or research settings must account for these limitations to ensure an accurate interpretation. This problem is not unique to this study, nor to the site of pressure measurement when dynamic activities are performed. High between-subject variability was observed when this same sensor (Egger et al., 2015; Shaw et al., 2014) and a similar sensor (Kruger et al., 2013) were used during different physical activities. High variability is also present when using an intra-gastric sensor to measure IAP during dynamic activities, because measures are influenced by variations in sensor orientation, gastric motility, and an individual's unique anatomical and physiological characteristics (Soucasse et al., 2022). The consistent presence of these challenges across both intravaginal and intra-gastric sensors highlights a fundamental limitation of what the sensors are measuring during dynamic activities and calls for cautious interpretation of the data collected using these methods. More thoughts and considerations for this tool are presented below.

As running speed increased, the intravaginal pressure sensor recorded higher pressures, but the increase was only significant when there was a large difference in running speed, from 7 km/h to 15 km/h, not from 7 km/h to 10 km/h or from 10 km/h to 15 km/h. This pattern suggests that a substantial increase in speed or effort may be required to elicit a significant rise in PFSP, and that changes in running speed of 3-5 km/h may not be sufficient to

yield a significant increase in pressure. This is attributed to the high between-subject variance noted above. Minimal detectable change and minimal clinically important difference for PFSP have yet to be established, so it is unclear what magnitude of change would be considered meaningful.

The amount of effort required during running at a certain speed may significantly contribute to PFSP, particularly depending on the runner's level of fitness. Although we standardized the level of exertion using the Borg Scale for a 30-minute run by asking the participants to run at a self-selected speed, the exertion level at the fixed speeds from 7 to 15 km/h could have varied among participants. Individuals with different fitness levels may experience different levels of exertion and, consequently, different PFSP responses. For example, while some runners easily completed the 2-minute run at 15 km/h, others had to stop because they were too out of breath or did not feel safe. Although these variations in exertion were not formally reported in our study during the incremental protocol, they should be considered in future research.

The sensor was expelled in nearly 15% of participants, predominantly among parous women, indicating a potential need for a redesign when considering using the sensor over a prolonged period of activity. While it is possible that the parous runners generated higher PFSP, leading to the expulsion of the sensor, it is more likely that anatomical changes in their tissues due to vaginal birth contributed to this issue (Van Geelen et al., 2018). These findings suggest that the design of the sensor should be reconsidered to ensure better retention or an alternative sensor placement, such as a rectal sensor, should be considered. The PF characteristics of participants who experienced sensor dislodgement are presented in section 7.1.4 below.

There were trends towards higher PFSP in runners with RI-SUI compared to continent runners, particularly when running at higher speeds and considering cumulative loading on the sensor (area under the curve). Although runners with RI-SUI and continent runners may exhibit

similar PFSP profiles at lower speeds, the increase in PFSP at higher speeds could potentially unmask a link between loading exposure and urine leakage, emphasizing the need to consider cumulative exposure over time rather than focusing solely on peak values and at high levels of exertion/speed. This could also explain why symptoms of urine leakage are more pronounced during high-level sport in the middle and at the end of a training session or competition (Carvalhais et al., 2018), as the cumulative load builds throughout the duration of the activity.

Overall, the findings of this study suggest that using an intravaginal sensor to measure PF loading during running is feasible but challenging due to high variance and issues with sensor expulsion. Also, pelvic accelerometry and PFSP appear to measure distinct aspect of PF loading, particularly during running. Further research is needed to validate this approach and develop more robust measures. The study also suggests that running at faster speeds may increase PF loading, and that runners with RI-SUI may experience higher loads on their PF, which could contribute to their leakage symptoms. However, many questions remain, and this led to the final research question of this dissertation: does PF loading experienced during running correlate with changes observed in PF morphometry and function after a run?

7.1.4 Is the extent of pelvic floor loading experienced by female runners associated with transient changes in pelvic floor outcomes after a run?

This last study of this thesis investigated the association between PF loading during running inferred by PFSP and pelvic accelerations, and transient changes in PF morphometry and function, as well as urine leakage, among female runners. Key findings were that faster pelvic accelerations were associated with a greater reduction in PF stiffness after the run, which accounted for 20 to 27% of the variance in the data, while this was not the case for PFSP. These effects were not evident in measures of pelvic support assessed using USI (i.e., BNH, LH or LP length). No relationship was found between PF loading measured during the run and the

extent of change in force generating capacity of the PFM's observed after the run. Interestingly, while some participants generated higher PFM force after running, others exhibited a decline, highlighting the complexity of muscle response to a 37-minute run. The variability in these outcomes suggests that factors other than the repetitive loading influence changes in muscle function on MVC. Further investigation is needed to understand the mechanisms driving these responses, which could involve individual differences in muscle endurance, recovery capacity, or neuromuscular adaptation.

When the BN was higher in the pelvis to begin with, it was displaced more caudally after the run, suggesting the importance of initial BN position as a factor in the amount of absolute change of BN position, however, BN position was not influenced by the extent of PF loading exposure measured through PFSP. The orientation of the PF and the specific forces acting upon it might also influence the outcomes. For instance, the BN could be subject to greater change in its position due to its anatomical positioning and the impact of vertical forces, which may alter its support mechanisms. In contrast, the LP, with its more horizontal orientation and active support function, may demonstrate less positional variation under similar conditions. Understanding these loading vectors and their dynamics is crucial to our understanding the impact of repetitive loading such as running on the PF.

In this study, despite the sensor being referred to by the developers as an IAP sensor, we chose to refer to the output as PFSP to more accurately reflect what it is measuring. While IAP traditionally refers to the pressure within the enclosed abdominal cavity, the sensor measures pressure applied to a probe located in the posterior fornix of the vagina. The probe is compressed and thus measures an increase in pressure when gravitational forces and inertia from the pelvic organs act on the sensor from above, and, on impact, the PF deforms the sensor from below. Vertical accelerations of the pelvic organs during running should increase the amount of pressure recorded by the sensor. Our terminology enhances clarity and ensures that

the term used to describe the measurement aligns with the anatomical location of the sensor, acknowledging that a combination of forces act on it to generate its output.

Overall, this study did not support recommendations to limit PF loading among females who engage in repetitive weight bearing activities such as running. While there is ongoing debate about the potential risks of running activities on PFD, it is crucial that we avoid fostering kinesiophobia, as the health benefits of staying active might outweigh the risks of running to PF health. Our data show that not all females experience negative changes in PFM function because of high PF loading as measured by PFSP and pelvic accelerations. Also, the effects measured in this study are likely transient. This highlights the importance of promoting balanced, evidence-based messaging when discussing the implications of running on pelvic health.

7.1.5 Integrated findings

The overarching goal of this PhD dissertation was to identify potential mechanisms underlying RI-SUI. Through this series of studies, the research provides compelling evidence that RI-SUI is a multifactorial condition and that predisposing characteristics in the PF may exist even before running, particularly lower tissue stiffness and more caudal positioning of the bladder neck, that might lead some females to leak urine during running. Importantly, the runners with RI-SUI who participated in the study had comparable running experience and volume as those without RI-SUI, suggesting that running alone does not cause these changes. Indeed, a longitudinal study would be needed to truly understand any cumulative effects of running on PF morphometry and function. We observed that while runners with RI-SUI exhibited less passive stiffness of their paravaginal tissues, there were also signs of adaptation in the active properties of their PFMs, including greater power generation. This may suggest that the muscles have adapted to the compromised support by enhancing their strength and power, or that by trying to remain continent during running, a training effect is experienced by the PFMs.

The research also revealed that running induces significant transient changes in the passive support structures of the PF of both incontinent and continent runners, and, while both groups experienced strain as a result of the running protocol, the runners with RI-SUI began with lower passive support. This predisposition suggests that, although both groups endure similar strain during running, those with RI-SUI may be more likely to cross a critical threshold where their continence mechanisms can no longer maintain continence, leading to leakage. These results also suggest that repetitive loading through running leads to a similar degree of decreased passive support in both groups of runners, indicating that running does not result in more pronounced changes in one group compared to the other. If runners who experience RI-SUI have larger levator hiatus' and longer LPs prior to a run compared to continent runners, the tissues might be in a lengthened position prior to a run. A review on the adaptations of skeletal muscles to mechanical stimuli proposes that if these muscles are overstretched (passive extension of muscle beyond its resting length) (Wisdom et al., 2015), there will be more sarcomeres in series and greater sarcomere length to restore force production in the new range of motion (Wisdom et al., 2015). This could in part explain why we did not observe a decrease in force generating capacity in incontinent runners despite decreased PF support. Given that EMG signals during running are contaminated by motion artefact and cross talk from nearby muscles, it remains unclear how the PFM behave during dynamic activities. i.e., are they active? And if so, do they contract concentrically, isometrically or eccentrically?

Although one study reported a positive relationship between weekly running distance and urine leakage (incontinent runners, n=11, mean=45.00 km/week; continent runners (n=17, mean=28.29km/week) (de Melo Silva et al., 2020), this does not establish causation and their sample of incontinent runners may have simply had more time to run during the study period. Additionally, potential selection bias cannot be ruled out as recruitment details were not provided and the groups may not have been recruited from the same sources (de Melo Silva et al., 2020). Another study using self-reported questionnaires found a higher frequency of urine

leakage in nulliparous competitive athletes compared to inactive or moderately active females, through which, the authors inferred that the high prevalence of urine leakage was associated with high training volume (Da Roza et al., 2015). Again, this finding should not be interpreted as causation. High-level competitive athletes may simply encounter more situations that cause leakage compared to less active females. Examining how variations in loading such as running distance, running frequency, speeds and time impact PF properties would also be valuable.

A notable trend was the differential impact of an acute bout of running on PFM strength and power between the groups. Runners with RI-SUI showed lower PFM strength and power after the run, potentially indicating fatigue, while continent runners exhibited increased strength, power, and endurance following the running protocol. These findings support both current hypotheses in the literature about the effects of repetitive high-impact loads on the PFMs: for some runners, loading may trigger a reflexive contraction that strengthens the muscles, while for others, it may lead to muscle fatigue. It is unlikely that muscles would get stronger after a 37-minute run, as such, these findings could be spurious, and more research with larger samples is needed. The alterations in the length-tension relationship induced by running, as observed on USI, may also explain why some runners can generate force more rapidly after the run, while others cannot. Overall, in this sample of female runners, running seems to exert a greater and more significant transient impact on the passive support structures of the PF, rather than significantly affecting the force generation capacity of the muscles.

The studies concurrently employed an intravaginal pressure sensor and a pelvic-mounted accelerometer to measure PF loading during running. These tools provided valuable insights. Based on the feasibility study, while both tools indicated a significant increase in PF loading exposure (accelerations and PFSP) with increased running speed, pelvic accelerometers appear to provide different information than the intravaginal pressure sensor. Although we observed trends toward higher PFSP in runners with RI-SUI compared to those without RI-SUI, this relationship was not significant but warrants further investigation. It is

uncertain whether runners with leakage adopt a particular running strategy that inadvertently increases loading over time, or if the increase in loading itself contributes to the development of SUI over the course of a run. Also, while we found some evidence of lower absolute change in passive stiffness after the run when pelvic accelerations were higher, it remains unclear if and how pelvic accelerations and PFSP might lead to RI-SUI. It is important to note that there was high variability in PFSP; while some runners had a large descent of their BN and a large increase in the area of their levator hiatus at low PFSP, some had almost no change in these measures despite being exposed to high PFSP. This further underlines the need for further investigation into the causal relationships between PF loading and continence mechanisms in female runners.

In summary, the findings from these studies provide a more nuanced understanding of RI-SUI than what was available at the start of the thesis, emphasizing the multifactorial nature of the condition and the critical role of pelvic organ support. The research also highlights the complexities of measuring and interpreting PF loading. The findings from this dissertation have important implications for the development of new treatment strategies for RI-SUI, as well as for the broader understanding of the pathophysiology of this condition.

7.2 Strengths & Limitations

7.2.1 Strengths

This research is pioneering in simultaneously assessing PF morphometry, function, and loading in female runners, offering a novel perspective on the mechanisms underlying RI-SUI by integrating biomechanics and pelvic health, advancing the field in a meaningful way. By employing a multifaceted approach, we were able to capture a more comprehensive picture of the underlying mechanisms of the PF of runners and their relationship with PF loading. This innovative work lays the groundwork for future research in this field, providing a robust framework for further exploration of RI-SUI. It also highlights key measurements, particularly the

morphometry, position, and movement of the BN as well as the passive properties of the PF, that are known contributors to SUI in the general female population (Falah-Hassani et al., 2021), and could be relevant to exercise-induced incontinence.

The use of state of the art, validated and reliable tools such as intravaginal dynamometry and USI, enhances the robustness of the findings. Recent research has confirmed that PF morphometry and function differ between the supine and the standing position (Forner et al., 2024; Gimenez et al., 2022; Huang et al., 2023). The inclusion of assessments in a standing position (intravaginal dynamometry, transperineal USI, PFSP, and pelvic accelerometers) was novel and to our knowledge, has not been used in any studies investigating PF properties of exercising females. Studies in which PF morphometry and function are assessed in a supine position while the exposure of the PF to loading occurs in an upright position, and while most participants experience symptoms or urine leakage in an upright position, risk missing important findings that may only be apparent in standing.

Although studies have previously investigated PFSP and pelvic accelerations among active females performing many activities (de Gennaro et al., 2017) and while three studies have investigated the relationship between continence (Campos et al., 2025; de Melo Silva et al., 2020), PFD (Coltman et al., 2025) and running mechanics, to our knowledge, no studies have looked at the relationship between the PF loading (as measured by PFSP and pelvic accelerations) and transient changes in PF characteristics. This thesis begins to fill this gap.

Another strength of this study is that we ensured that participants had high exposure to high impact loading, maximizing our ability to detect meaningful differences. By using strict inclusion criteria such as engaging in a high-impact activity (running) regularly (2 or more times a week) and for a sustained period of time (more than 1 year), we are confident that the PF of all participants had been subjected to significant PF loading. As a next step, recruiting sedentary females and using similar methods to assess the PF would allow us to evaluation potential

cumulative effects of running on the PF, to determine if a larger and more costly longitudinal study is warranted.

Although this dissertation provides valuable insights that advance our understanding of the mechanisms underlying RI-SUI, it also has limitations that need to be acknowledged.

7.2.1 Limitations

7.2.1.1 SOURCES OF BIAS

One of the primary limitations across all four studies is the recruitment bias inherent in cross-sectional designs (Mann, 2003). The female runners who participated in the laboratory assessments were likely already interested in their pelvic health, potentially skewing the sample. Additionally, considering that approximately 23% of women with urinary symptoms discontinue running due to their condition (Dakic et al., 2021), our sample may be biased toward those with less severe symptoms, as those with more pronounced UI may have already stopped running, and thus would not have met our strict inclusion criteria. Consequently, the actual differences in PF morphometry and function that occur as a result of a bout of running, as well as the PF loading experienced during running, and differences between runners with and without running-induced RI-SUI might be greater than what was observed here.

Another limitation is that parity was not matched between continent and incontinent runners, which could have influenced the findings. Parity can significantly affect PFM morphometry and function (Fang et al., 2023; Grinbaum et al., 2023; Myer et al., 2018), thus differences in parity between the groups may have influenced the observed differences between continent and incontinent runners. Unfortunately, we did not have the statistical power to perform a subgroup analysis based on parity. However, as a verification step, we did explore the impact of parity by disaggregating the sample and analyzing the results of both the nulliparous and parous participants separately. Interestingly, the same trends were observed

between runners with and without leakage, but the data were skewed towards less passive support among parous runners. These findings suggest that while parity may be a relevant factor, the trends in PF changes that occur over the course of a run remain consistent regardless of parity. Further, the retention of the PFSP was problematic among some parous runners, which further complicates interpretation. While our results provide valuable insights, the limitations related to parity need to be considered when interpreting the observed effects.

Another notable limitation of our study is the homogeneity of our sample, which primarily consisted of very active, high-mileage White runners who were mainly pre-menopausal. This narrow demographic focus limits the generalizability of our findings to other groups, including recreational runners who may engage in running less frequently or at lower intensities, and, as noted above, those who have stopped running because of their UI symptoms. Additionally, our results may not apply to older runners, particularly post-menopausal women, who might experience different PF responses due to age-related changes in muscle function, hormonal status, and connective tissue integrity (Mannella et al., 2013; Trowbridge et al., 2007). It is possible that different trends might emerge in these populations, or in different ethnic groups where it has been shown that the prevalence of PFD differs compared to White females (Gonzalez et al., 2022). We also recognize that there are disparities in PF research in ethnic communities that need to be further addressed (Mou et al., 2024). Future research should aim to include a more diverse sample to better understand the effects of running on PF health across different age groups, races or ethnicities, and levels of physical activity.

7.2.1.2 Tools and techniques

The use of four distinct instruments to assess concurrently PFM characteristics and PF loading represents a major strength of this study, nonetheless, it is important to recognize the inherent limitations associated with each of the instruments used.

i. Intravaginal dynamometry

Intravaginal dynamometry measures the forces exerted by the PF (Deegan et al., 2018; El-Sayegh et al., 2023). During passive elongation, the measured forces can be influenced by the connective tissues at the introitus or within the vaginal wall (Deegan et al., 2018; El-Sayegh et al., 2023). When using dynamometry to measure PFM contractile strength, the downward forces exerted by abdominal and pelvic organs can influence the force readings (Deegan et al., 2018; El-Sayegh et al., 2023). Despite these limitations, intravaginal dynamometry has been shown to be more valid, reliable and sensitive than bidigital assessment and vaginal manometry (Deegan et al., 2018; El-Sayegh et al., 2023; Navarro Brazález et al., 2018). Although some individuals may find intravaginal dynamometry uncomfortable or invasive, potentially affecting their willingness to participate or their ability to perform contractions effectively, this was not a significant issue in the current study. Efforts were made to ensure the procedure was as comfortable as possible for participants, such as allowing them to gently guide the intravaginal dynamometer arms inside their vagina with the researcher. The dynamometer used in this work was custom built, validated using bench testing, and had strong test-retest reliability (Bérubé et al., 2018; Czyrnyj et al., 2021). However, as a custom, automated tool, we encountered several technical issues stemming from unstable connectors, which resulted in some participants not completing the dynamometry trial. This was particularly problematic during the COVID-19 pandemic, as there was no availability of on-site engineers to troubleshoot when problems arose.

ii. Transperineal ultrasound imaging

Transperineal USI, while a valuable tool for assessing PF morphometry, has several limitations that must be considered (Dietz, 2017). One significant limitation is that the quality of the imaging is highly dependent on the operator's skills and experience, introducing variability in technique, probe positioning, and image interpretation that can affect the consistency and

validity of the results (De Marzi et al., 2022). In our sample, capturing all relevant landmarks in a single frame when imaging with participants in a standing position proved particularly challenging due to the multiplanar relationships among the pelvic structures of interest. This was even more difficult after the run when the tissues had experienced strain. This limitation was addressed by doing more than 200 hours of training in USI under the supervision of experts in the field and practicing the techniques during other laboratory activities. Another limitation is that changes in the levator hiatus area measured during the MVM in standing might be compromised by co-contraction of the PFM. While both running groups were provided with extensive cueing and feedback using USI on how to perform a proper MVM with concurrent PF relaxation, consistent with several previous reports (Baessler et al., 2017; Örnö & Dietz, 2007; Thibault-Gagnon et al., 2014; Thyer et al., 2008), a co-contraction of the PFM was observed in 9 out of 20 continent runners (45%) and in 6 of 19 incontinent runners (32%). While we chose to include the MVM task to reflect the maximal extent to which the connective tissues of the PFM can lengthen, levator ani co-contraction might have limited interpretability.

iii. Inertial motion units

A systematic review concluded that GRFs can be predicted, with varying degrees of accuracy, from inertial motion units, by using inverse kinematics, machine learning and/or biomechanical models, particularly for the vertical component of the GRF experienced during single limb stance tasks like walking and running. While providing valuable data on skeletal biomechanics, several notable limitations must be considered. One primary limitation is that acceleration provides an indirect measurement of GRF, which can limit validity (Ancillao et al., 2018). Although we explored the possibility of estimating GRF from pelvic accelerometry by collecting concurrent force plate data during running trials over a force plate using an individual regression model for each participant, we observed a heteroscedastic effect at higher acceleration magnitudes, suggesting that this approach may only be valid for running at lower accelerations. Additionally, accelerometers are sensitive to movement artifact, such as shifts in

sensor position or variations in body movements, which can introduce noise and affect data validity, particularly during high-impact activities such as running (Godfrey et al., 2008). To address this, we securely fixed the sensor to a stable bony landmark and applied a filter to attenuate noise associated with soft tissue vibration. Integrating pelvic accelerometers with direct force measurements (i.e. instrumented treadmill) and motion capture in a fully equipped biomechanics laboratory would have provided a more comprehensive assessment of potential differences in kinetics and kinematics between runners with and without RI-SUI. The data in this thesis were collected with the intention of using them to decide whether a full biomechanical assessment might be warranted. Unfortunately, the feasibility of a more complete biomechanical assessment was constrained by logistical and resource limitations.

Iv. Piezoresistive pressure sensor

Using PFSP to infer PF loading also involves several limitations, both related to the tool itself and the inherent challenges of interpreting the data (Hamad et al., 2013). While the pressure recorded using this tool has been referred to in the literature as IAP, this is a misnomer. The sensor records the summed forces acting to compress it, meaning that forces can be applied from any structure surrounding the sensor, including forces generated by intra-thoracic pressure changes, abdominal muscle contractions and hip muscle contractions (Niederauer et al., 2023), gravitational loading of the pelvic organs onto the sensor, and impact loading of the sensor during high-impact activities. Further, the sensor output does not directly measure the load on the PFMs and their connective tissues. Variations in sensor placement, as well as individual anatomical differences, can further impact the data collected. To account for this, the baseline pressure measurements was removed from the peak pressure recorded and sensor placement was confirmed both before and after the running task.

7.2.1.3 Study protocol

Despite thorough planning and rigorous execution of this study, various challenges emerged that impacted the data collection process. By examining these limitations, we aim to provide a comprehensive understanding of the potential influences on the study's findings and offer insights into areas for improvement in future research.

The lack of standardization of running speed during the steady-state 30-minute running speed could be considered a limitation. Participants selected their own running speed to achieve comparable levels of exertion, targeting a rating of 15-16 on the Borg Scale. In study two, runners without RI-SUI chose a faster treadmill speed (10.8 km/h) compared to their incontinent counterparts (9.7 km/h). Despite this difference in speed, step counts during the running protocol were similar between the groups, indicating that both groups were exposed to a comparable number of impacts. If runners with RI-SUI had run at the same speed as their continent peers, it is possible that greater differences between the groups would have been observed. We chose to standardize the effort rather than the speed to allow participants to load their PF in a manner consistent with their usual training. For instance, if a runner accustomed to running at 14 km/h was restricted to a standardized speed of 10 km/h for the 30-minute duration, they might not experience urinary symptoms during the run, as the reduced intensity might not sufficiently overload the continence system. Our approach ensured that participants were exerting comparable levels of effort, reflecting their typical exercise experience. To account for differences in running speed, we implemented an incremental running protocol with speeds of 7, 10, and 15 km/h. This approach allowed us to make between-participant comparisons at these speeds, thereby standardizing the conditions for evaluating the PF loading across different participants.

Since the dynamometry assessments were always conducted after the ultrasound, there is a possibility that the PFM may have recovered function during the USI evaluation. Although we aimed to complete the tasks as quickly as possible, it is known that the recovery of muscle fatigue begins immediately after the exercise is finished, and partial recovery will be evident

within 5 minutes (Carroll et al., 2017). While we recorded strength as soon after the running bout was finished as possible, the time interval was approximately 15 minutes, thus some recovery would have occurred. Complete recovery of muscle function may take several hours (Carroll et al., 2017), however this short recovery period could have introduced a bias toward observing less change in active muscle properties after the run than what actually occurred. However, in balancing several constraints, we chose to perform the imaging assessment first to ensure that we captured the morphometry of the PF before stretching the tissues with the intravaginal dynamometer.

Several participants with RI-SUI did not leak urine during the treadmill protocol. Thus, we did not capture data from participants with RI-SUI after their continence system was pushed to failure. Exploring this threshold and investigating the PF morphometry and function after continence failure might reveal key mechanisms underlying RI-SUI and factors that contribute to the onset of urine leakage. We recommend as a next step generating a running protocol that ensures that all participants leak urine prior to its completion. This avenue of research could be extremely valuable in understanding RI-SUI and possibly developing targeted interventions for individuals who experience symptoms.

7.3 Clinical Implications

Based on the overall results of this doctoral thesis, treatment strategies aimed at enhancing pelvic organ support, particularly the bladder neck, which appears to be a key component implicated in RI-SUI, could be a promising avenue for conservative intervention. Given that we found that running induces transient changes experienced mainly as a loss of passive support, it is crucial that interventions address this vulnerability. By supporting the pelvic organs during physical activity, it may be possible to prevent the pelvic structures from reaching a critical strain threshold where they can no longer maintain continence. If PFM training does improve morphological features of the PF such as a significantly higher BN, a smaller levator

hiatus area and thicker external urethral sphincter, which could all contribute to maintaining continence in the general female population (Bø, 2024), than incontinent runners that present with compromised pelvic organ support might benefit from such an intervention.

Recent reviews have highlighted that, despite various limitations in methodologies, PFM training and other conservative strategies, such as the use of pessaries, may be effective in alleviating symptoms of UI in females who engage in regular exercise (Demeco et al., 2024; Petter Rodrigues et al., 2024; Romero-Franco et al., 2021). These reviews suggest that PFM training, whether used alone or combined with tailored conservative approaches, can lead to significant improvements in UI symptoms in female exercisers. However, most of the individual studies included in these reviews were not randomized controlled trials and had high risk of bias. A randomized-controlled trial published after these systematic reviews suggested that urine leakage improves with PFMT compared to no intervention in female exercisers (Skaug et al., 2024), however, the reduction in symptoms reported on the ICIQ-UI-SF after the intervention did not reach the minimally important difference previously reported for this questionnaire (Nystrom et al., 2015). The objective improvements in urinary symptoms reported in some individual studies warrant careful interpretation. For instance, some studies report improvement in urinary symptoms based on a significant reduction in pad weight after PFMT intervention, however, baseline pad test values ranged only from 1 to 4.5 grams (Ferreira et al., 2014; Pires et al., 2020; Sousa et al., 2015). Given that the pad test during physical activity remains controversial and may be influenced by vaginal discharge, perspiration, and other fluids, caution is needed when interpreting these studies and the conclusions of the systematic reviews. A recent sensitivity and specificity analysis indicated that using a cut-off of 9.35g during a 38-minute treadmill run yields a sensitivity of 70% and a specificity of 88% for predicting urine leakage (Petter Rodrigues et al., 2025). Notably, some continent runners had pad weight gains near 20g probably due to perspiration alone (Petter Rodrigues et al., 2025).

It remains unclear whether female athletes benefit from PFM exercises to overcome urine leakage while running. If their muscles are already stronger, have more capacity to contract rapidly, and have more endurance than those of their continent counterparts, increasing PFM strength may not be the mechanism through which PFMT may be effective (Acevedo-Gómez et al., 2024; Gan & Smith, 2023). A recent review analyzed potential mechanisms through which PFMT is believed to work and found lack of clear empirical support for any of them (Sheng et al., 2022). These included that PFMT enhances PFM strength and that it improves PFM coordination and timing (Sheng et al., 2022). The potential effects of PFM training may also be that they increase the tensile strength of the passive support structures. A recent narrative review suggested that PFMT induces significant changes in the PFMs and urethral sphincter including BN elevation, a reduction in the levator hiatus size, and hypertrophy of the levator ani and striated urethral sphincter (Bø, 2024). However, these studies examined the PF of females with and without symptoms of UI in the general population and not specifically in the athletic female population.

Various vaginal inserts such as pessaries, tampons are thought to provide mechanical support to the vaginal wall that can support the urethra and contribute to symptom relief in female exercisers. While no randomized controlled trials have been conducted in the athletic female population, the overall evidence supports intravaginal pessaries as a potential tool in managing UI and enhancing quality of life for active females (Petter Rodrigues et al., 2024). Emerging techniques such as laser therapy and running retraining for alleviating UI symptoms in active females require further research as current evidence is limited to case reports (Okui et al., 2023; Steimling et al., 2023).

SUI in female athletes appears to be a multifactorial condition, with significant variability observed among runners. Some individuals experience substantial changes in their PFM even at low levels of PF loading, while others show minimal change even under high PF loading conditions and we did not observe any correlation between PF loading and pad weight gain

among the runners with RI-SUI. This variability suggests that intrinsic characteristics of the PFM may play a crucial role in contributing to leakage. For runners with compromised PFM function or support, where the muscles and connective tissue can no longer effectively prevent leakage under PF loading, incorporating strategies to manage and reduce PF loading in parallel with improving pelvic organ support could be beneficial.

While two recent studies found no difference between running kinematics and kinematics between runners with and without PDF (Campos et al., 2025; Colman et al., 2025), one of the two identified a decreased ability to attenuate shock absorption in the lower limbs of incontinent runners. This novel research suggests that while PFM function and other muscles of the trunk, hips, and legs as well as GRF are no different between the groups, the reduced impact absorption during running might place greater mechanical demand on the PF. Including strategies that improve shock absorption in their rehabilitation plan could potentially decrease loading and improve the effectiveness of the continence system, as demonstrated in a case report highlighting positive outcomes from adjusting loading conditions (Steimling et al., 2023).

7.4 Future directions

Research in the field of athletic incontinence is emerging as there is global recognition that much needs to be done to understand and manage this condition. Future research should use the studies presented in this thesis to build upon and to avoid pitfalls. Given the multifactorial nature of SUI, employing multivariate approaches could be instrumental to identifying predominant elements that significantly influence the continence system during exercise activities. This approach would allow researchers to discern which factors are most critical for maintaining continence, as some runners may be able to compensate for the loss of passive support up to a certain threshold, beyond which additional support or intervention may no longer yield improvements. By understanding the interplay among variables, targeted

strategies can potentially be developed based on incontinence phenotype to enhance continence outcomes more effectively in female athletes.

As noted throughout this discussion, longitudinal studies are essential to deepen our understanding of the long-term impact of running on the female PF. Currently, we know that UI is prevalent among female exercisers, particularly during running, and that an acute bout of running causes a transient loss of passive support of the pelvic structures in both runners with and without RI-SUI. However, this effect appears to be related only partly to the amount of PF loading experienced during the run. To better assess the risks and benefits of running on PF health, it is essential to track the PFM characteristics of females who have never run and follow them as they start a running training program and continue it over an extended period. By evaluating how running-induced loading impacts the PF in the long term, researchers could provide more informed recommendations about the potential benefits and risks associated with running for female pelvic health. Such studies would offer critical insights into if and how prolonged exposure to running affects PF integrity and would contribute to evidence-based guidelines for managing and mitigating the risk of UI among female runners.

7.5 Concluding remarks

This dissertation offers a comprehensive examination of the predisposing characteristics thought to contribute to RI-SUI in female runners and the magnitude and impact of PF loading during an acute run on the pelvic organ support and PFM function. Overall, this research provides a strong foundation for understanding the impact of running on PFM morphometry and function and the findings highlight the need to develop more robust methods for measuring PF loading and to better understand the complex interplay between PF structure, function, loading exposure and RI-SUI. Given all that remains unknown, encouraging females to remain active

while considering individualized approaches to training and recovery is key to avoid unnecessary fear of RI-SUI and ensuring that physical activity remains a positive component of their overall well-being.

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Appendix A: Ethics Approval

19/08/2019

Université d'Ottawa

Bureau d'éthique et d'intégrité de la recherche

University of Ottawa

Office of Research Ethics and Integrity

CERTIFICAT D'APPROBATION ÉTHIQUE | CERTIFICATE OF ETHICS APPROVAL

Numéro du dossier / Ethics File Number

H-06-18-759

Titre du projet / Project Title

Mechanisms underlying
running-induced urinary
incontinence in women

Type de projet / Project Type

Recherche de professeur /
Professor's research project

Statut du projet / Project Status

Renouvelé / Renewed

Date d'approbation (jj/mm/aaaa) / Approval Date (dd/mm/yyyy)

19/08/2019

Date d'expiration (jj/mm/aaaa) / Expiry Date (dd/mm/yyyy)

30/07/2020

Équipe de recherche / Research Team

**Chercheur /
Researcher**

Affiliation

Role

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Chercheur Principal / Principal
Investigator

Marie-Ève BÉRUBÉ

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CERTIFICAT D'APPROBATION ÉTHIQUE | CERTIFICATE OF ETHICS APPROVAL
Numéro du dossier / Ethics File Number

H-06-18-750

Titre du projet / Project Title

 Mechanisms underlying
 running-induced urinary
 incontinence in women

Type de projet / Project Type

 Recherche de professeur /
 Professor's research project

Statut du projet / Project Status

Renouvelé / Renewed

Date d'approbation (jj/mm/aaaa) / Approval Date (dd/mm/yyyy)

13/09/2019

Date d'expiration (jj/mm/aaaa) / Expiry Date (dd/mm/yyyy)

30/07/2020

Équipe de recherche / Research Team
**Chercheur /
Researcher**
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Marylène
CHARETTE

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Étudiant-chercheur /
Student-researcher
Conditions spéciales ou commentaires / Special conditions or comments

MSc students Elisabeth Mai Le, Samantha Poulin and Yostina Guirgues have been added to the research team.

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H-06-18-750

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Mechanisms underlying
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Professor's research project

Statut du projet / Project Status

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Date d'approbation (jj/mm/aaaa) / Approval Date (dd/mm/yyyy)

27/07/2020

Date d'expiration (jj/mm/aaaa) / Expiry Date (dd/mm/yyyy)

30/07/2021

Équipe de recherche / Research Team

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Student-researcher

Conditions spéciales ou commentaires / Special conditions or comments

This certificate is issued with the understanding that the Principal Investigator is responsible for the following:

1. ensuring that the research protocols comply with the most up-to-date advice, recommendations, directives, orders, advisories, guidelines about the spread of COVID-19 from government and public health officials and with those from institutions, organizations or funding agencies relevant to the research; and
2. establishing, maintaining and implementing an up-to-date continuance plan that includes reasonable precautions to help prevent the spread of COVID-19 to participants, research team members and ensure safe research practises, for example, training of research team members, use of personal protective equipment, standards of sanitization, handwashing and physical distancing.

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Appendix B: Letter of information (English)

Version 2 – 11/02/2019



Letter of Information

Title of the Study: Mechanisms underlying running-induced urinary incontinence in women

Principal Investigator: Linda McLean, PhD, Full Professor, School of Rehabilitation Sciences, University of Ottawa.

Doctoral candidate: Marie-Eve Bérubé, MScPT, School of Rehabilitation Sciences, University of Ottawa,

Background Information

Many women leak urine when they perform tasks such as coughing, sneezing, or physical exercise. Urine leakage is associated with increasing age, body weight, giving birth, and smoking. The pelvic floor muscles, which are located at the base of the pelvis, are important in helping to maintain bladder control, but their role is not well understood. Through this study we are investigating the structure and function of the pelvic floor muscles in women, and we are comparing them between women who do and who do not experience urine leakage while running. It is expected that the results of this study will allow us to identify specific structural and functional characteristics of the pelvic floor muscles that are related to their capacity to prevent accidental urine leakage during physical activity.

A research assistant will read this consent form with you and answer any questions you may have. The research ethics board from the University of Ottawa has reviewed the ethical components of this study and has found it to be in compliance with national standards.

We are aiming to recruit a total of 105 female volunteers in the Ottawa-Gatineau area, 35 women who run on average at least 10km per week and who report urine leakage during running, 35 women who run on average at least 10km per week but who have never experienced urine leakage while running, and 35 healthy women who do not leak urine and who do not exercise regularly. You have been invited to participate in this study because you fall into one of these three groups.

Purposes of the Study

Through this study we aim to understand the relative contributions of the pelvic floor muscles and associated connective tissues to urine leakage during running.

The study will involve the completion of seven on-line questionnaires (approximately 1 hour) and one laboratory evaluation session lasting approximately 2.5 hours.

Questionnaires

If you agree to participate, you will receive access to seven on-line questionnaires through an e-mail link. You may request to receive paper copies of the questionnaires by mail or fax instead. The questionnaires should take you no more than 1 hour to complete. These questionnaires will ask you questions about (1) your quality of life, (2) your medical history, (3) bowel functioning, (4) bladder functioning, (5) your lifetime physical activity profile, and (6) your risk factors for exercise. You will need to fill out all of the questionnaires before attending the laboratory session. If you fill out the questionnaires by pencil and paper, you will be asked to mail them to the research team before your assessment is scheduled as your answers will be reviewed by the research team to ensure that you are eligible to participate before your laboratory appointment is scheduled. On one of the questionnaires, the Par-Q, if you score more than zero you will not be invited to attend the laboratory session as this score indicates that the assessment protocol may place you at risk for heart symptoms. On a second questionnaire, the LEAF questionnaire, if you score more than eight, you will not be invited to participate as this indicates that you might be exercising to an extent that your body's hormone systems are out of balance, which might influence the findings of this study. If you are not invited to attend the laboratory session, you will be informed why. If you meet our eligibility criteria, you will be invited to attend the laboratory assessment.

Laboratory Assessment

This session will take place at the Motor Function Measurement Lab at the University of Ottawa at 200 Lees Ave. in Room E155D. The session will last approximately 2.5 hours.

A graduate student and research physiotherapist, Marie-Eve Bérubé will perform all assessment procedures at the laboratory assessment. Marie-Eve is a physiotherapist registered with l'Ordre Professionnel de la Physiothérapie du Québec, and is recognized as a pelvic floor therapist. She has more than three years of experience with the evaluation procedures that are used in this study. Ms. Bérubé will be assisted by a research assistant who will help to prepare instrumentation and will operate computers but who will not perform any clinical assessment techniques.

You will be asked to empty your bladder 1 hour prior to your scheduled appointment, and to drink 350ml of water immediately afterwards. Please avoid drinking any tea, coffee or energy drinks 3 hours prior to participating in the study as they may make you have an urge to void that would interfere with the study protocol. On site, Ms. Bérubé, will measure your height, weight, waist circumference and hip circumference. You will then be left in a private area to undress from your waist down and will be given a gown to cover yourself. When you are ready, you will invite Ms. Bérubé and her assistant back into the assessment room. You will lie on your back with a pillow behind your head. Ms. Bérubé will complete a standard physiotherapy examination of your pelvic floor muscles. Ms. Bérubé will test your ability to sense a light touch on your inner thighs to ensure that you have no problems with the nerves that provide sensation to your pelvic floor. A reflex will be tested through gentle stretching and tapping motions on your perineum. Next, Ms. Bérubé will feel your pelvic floor muscles using two gloved fingers inserted into your vagina. With Ms. Bérubé's fingers in place, you will be asked to contract your pelvic floor muscles as strongly as possible so that your strength can be evaluated, and then you will be asked to relax your pelvic floor muscles while a gentle stretch is applied to your vaginal opening to evaluate the flexibility of your pelvic floor muscles. You may ask to stop or to slow the testing down at any time.

At this point, it is possible that you will be withdrawn from the study if Ms. Bérubé determines that you have abnormal sensation or pelvic floor reflexes or any anatomical variations such as a pelvic organ prolapse. If your participation is discontinued, Ms. Bérubé will advise you to consult with your regular health care provider (physician or nurse practitioner) and will tell you why. She will answer any questions or concerns you might have before ending the session. If you are withdrawn from the study, we may seek your permission to keep your name and contact information on file in order to contact you to see if you are interested in future studies in our laboratory. If you do not agree to allow us to keep this information, then it will be permanently removed from our records, and we will not contact you again.

If you are eligible to continue, Ms. Bérubé will assess your pelvic floor muscle strength and stiffness using a device called dynamometer, which will resemble a routine PAP test, except that you will be standing. You will stand leaning against the examination table. The dynamometer arms will be covered in condoms and you will be asked to guide them into your vagina. Ms. Bérubé will ensure correct positioning and will hold the device at a comfortable angle. The dynamometer arms will then be opened slowly and you will be asked to perform three maximum effort voluntary pelvic floor muscle contractions, whereby you try to close the arms. The arms of the dynamometer will then be closed and the device will be removed.

You will next be asked to lie down on an examination table with your head supported and your trunk inclined. Two sticky electrodes will be placed on the skin near your anal region and another will be placed near your hip. You will again be asked to guide the dynamometer arms inside your vagina. You will be asked to keep your pelvic floor muscles completely relaxed while the arms of the dynamometer open for five seconds to stretch your pelvic floor muscles, and then close. This stretch will be repeated three times and then the dynamometer will be removed from your vagina. For safety purposes, the dynamometer is battery operated and has limits such that the arm opening cannot overstretch or pinch your tissues. Additionally, you will be given a safety switch that automatically closes the dynamometer arms and shuts off the system at the push of a button—this device will remain in your hand during all testing and you will be shown how to use it.

Next Ms. Bérubé will measure your bladder volume by placing an ultrasound sensor over your abdomen, similar to how an ultrasound picture is used to evaluate a baby when a woman is pregnant. The ultrasound will be used to confirm that your bladder has a moderate amount of urine in it—if your bladder is not full enough, you will be asked to drink a small amount (1/2 cup) of water and to wait 20 minutes; if it is too full, you will be asked to go to a nearby washroom and to void a small amount. When your bladder has the right amount of urine, you will undergo ultrasound imaging of your pelvis while you are in a standing position. Ms. Bérubé will give you clear instructions and will help you to practice each task before the ultrasound images are taken. The ultrasound assessment involves placing an ultrasound probe covered by a condom and gel over your genital area. The probe is not inserted into your vagina—it simply rests against your skin. Pictures will be taken while you stand, while you contract your pelvic floor muscles, and while you bear down. Each task will be repeated three times. This will conclude the pre-run assessment. Again, you may ask to stop or to slow the testing down at any time.

You will next prepare for the running task. You will be instructed to insert a small pressure-sensing device, similar to a tampon with wires attached, into your vagina while you are lying down or standing, depending on your preference. Ms. Bérubé will look to verify that you have inserted the device correctly and then you will be asked to put your underwear on, which will have an

incontinence pad adhered inside. You will then put on a pair of tight (lycra) running shorts which will hold the wires of the pressure sensor in place. With the sensor in your vagina, you will lie down on the examination plinth for 10 minutes while the sensor warms up to match your body temperature. You will then stand up and perform a series of coughs, bearing down maneuvers, jumps, and to lift small fifteen pound weights. This will ensure that the sensor is not going to fall out during the running task. After these tasks, Ms. Bérubé will check to see if the sensor descended, and if it did, it will be reinserted and the process will be repeated. If the sensor still descends, it will be removed and we will not record pressure while you run; you will not be withdrawn from the study.

Lastly, a small device called an accelerometer, will be taped to your skin at the left side of your pelvis and two thin shoe insoles will be placed in your running shoes. You will also have to wear a Fitbit on your wrist. Prior to running on the treadmill, you will need to walk 5 times and jog 5 times across a ramp that will be set up on the floor. Then, you will stand on the treadmill and you will be instructed by the research assistant on how to increase the treadmill speed to move from walking to a slow jog, stopping at a speed of 7km/h. At this speed, you will jog for 2 minutes, then you will increase the treadmill speed to 10km/h, run for 2 min, and then increase the speed to 15km/h and run for 2 minutes. At this point you will be instructed to increase or decrease the treadmill speed such that you are running at a speed where you rate the running task as somewhat hard. Two short video clips will be taken of you while you run at this pace for 30 minutes, after which time you will slow the pace down to 10km/h and jog for 30 sec, then to 7km/h and jog for 30 sec. If you feel shortness of breath or discomfort during the running task, you may slow your pace, or, if necessary, walk for one minute before resuming the same running pace or a slower pace. While running, you will be asked to report any instances of urine leakage. Water will be provided if you feel you need it.

Immediately (within 30 seconds) following the running task, the incontinence pad will be removed from your underwear and weighed, the intra-vaginal sensor, the accelerometer and the shoe insoles will be removed and the ultrasound imaging and dynamometer protocols will be repeated in the same order. At this point, you will also have to rate your fatigue using a scale that will be provided to you.

Risks

Even if you are pregnant and are not aware of it, the techniques used in this study do not pose any known risks to a developing fetus. That said, please do not volunteer to participate if you know that you are pregnant.

There are no known risks to any of the testing procedures used in this study. The dynamometer used to measure pelvic floor muscle strength should not cause any discomfort at any time. You may experience the sensation of stretching when the device opens as it applies a stretch to your pelvic tissues, this should feel the same as stretching any other muscle or tissue in your body. As noted, you will be provided with a shut off switch, which will allow you to close the device at any time if you feel worried or uncomfortable.

Ultrasound imaging has not been found to be harmful to humans in any way. To minimize the risk of infection, the ultrasound probes are covered with a condom during use, and, between

participants, are sanitized according to established infection control standards provided by the manufacturer. The dynamometer arms are used only once then are discarded. They are printed in a biocompatible plastic (PLA) and are covered with latex-free condoms, again to minimize any risk of infection or reaction. The pressure sensors are used only once then are reprocessed, again to minimize any risk of infection or reaction.

During the bearing down manoeuvre you may experience some light headedness. If you are feeling dizzy or require a break, please let the researchers know. You will be given ample time to rest between trials to avoid causing this feeling.

Although unlikely, in the event of any research-related injury (for example, through a trip, slip or fall while you are attending the laboratory assessment session), you will be referred to your regular health care provider to receive appropriate medical treatment/care through your provincial health plan. If urgent care is required, we will contact University of Ottawa Campus security and you will be escorted by the research staff to the Emergency Department of the Ottawa General Hospital to receive care. You are not waiving your legal rights by agreeing to participate in this study. As a graduate student and a physical therapist, Ms. Bérubé is specifically trained to perform the pelvic floor muscle assessments used in this study.

Benefits

Participation in this study will allow you to learn about the state of your pelvic floor musculature. You will be taught how to perform a proper pelvic floor muscle contraction, and will receive feedback from a pelvic floor physiotherapist.

Compensation

You will not be paid to participate in this research.

Withdrawal from Study

You have the right to withdraw your participation from this study at any time and without providing any reason. If you choose to withdraw from the study, any data provided by you will be destroyed unless you provide permission to our team to retain and use them.

Confidentiality

You will not be identifiable in any publications or presentations resulting from this study. No identifying information will leave the University of Ottawa. There will be one password-protected electronic file, stored on an encrypted computer in the Motor Function Measurement Lab, which will link your name to your participant number. This file will only be accessible by Dr. McLean and her staff and students at The University of Ottawa who have all been instructed on proper procedures for protecting privacy and confidentiality and who have provided signed confidentiality agreements. All electronic records will be stored in a secure database at the University of Ottawa and will be protected by a user password, again only accessible by Dr. McLean and her students and staff. All paper records will be stored in a filing cabinet within the Motor Function Measurement Lab, which is a restricted access area. All files will be kept for a period of 10 years after the study has been completed. At the end of the retention period, all paper records will be disposed of in confidential waste or shredded, and all electronic records will be permanently deleted from the data server.

Participant Rights

Your participation in this study is voluntary. You may withdraw from this study at any time. You are free to choose not to answer any questions or not to complete whole questionnaires. You are free to refuse to undergo any aspect of the testing, without giving any reason. The researchers may withdraw you from the study for scientific reasons at any time. In this case, they would give you a clear and valid reason. You have the right to obtain copies of any study forms that contain your personal information.

As a participant in this study, you have the right to an environment that you feel comfortable in. For your safety and for the safety of our team, we will have a third person (female student research assistant) present in the evaluation room during all assessment procedures. You may also bring a friend or family member with you to be present in the room if this makes you feel more comfortable.

If at any time, you have further questions or problems you can contact the study investigators:

Linda McLean, PhD at

or

Marie-Ève Bérubé, PT, PhD candidate

or

If you have any questions about this study or if you feel that you have experienced a research-related injury, please contact _____ at your earliest convenience.

The University of Ottawa Sciences and Health Sciences Research Ethics Board has reviewed this protocol and has found it to comply with standards for ethical aspects of research studies involving human participants at The University of Ottawa. If you have any questions about your rights as a research participant, you may contact the Protocol Officer for Ethics in Research at the University of Ottawa, at 613- 562-5387 or ethics@uottawa.ca.

Appendix C: Letter of information (French)

Version 2 – 11/02/2019



Lettre d'information

Titre de l'étude: Mécanismes sous-jacents à l'incontinence urinaire durant la course chez les femmes

Chercheuse principale: Dre Linda McLean, PhD, professeure titulaire, École des Sciences de la Réadaptation, Université d'Ottawa,

Candidate au doctorat: Marie-Ève Bérubé, MScPT, École des Sciences de la Réadaptation, Université d'Ottawa,

Contexte de l'étude

Plusieurs femmes éprouvent des fuites d'urine lorsqu'elles toussent, qu'elles éternuent, ou font de l'activité physique. Les fuites urinaires sont associées à l'âge, au tabagisme, au poids corporel et à l'accouchement. Les muscles du plancher pelvien, situés à la base du bassin, sont essentiels au maintien du contrôle de la vessie. Par contre, leur rôle n'est pas bien compris. Cette étude nous permet d'évaluer la structure et la fonction des muscles du plancher pelvien chez la femme, et de les comparer à des femmes qui ont des fuites urinaires durant la course, à celles qui n'en ont pas, ainsi qu'à des femmes qui ne font pas d'exercice. Nous nous attendons à ce que les résultats de cette étude nous permettent d'identifier les structures spécifiques ainsi que les caractéristiques fonctionnelles des muscles du plancher pelvien et de leur capacité à prévenir les fuites urinaires accidentelles durant l'activité physique.

Une assistante à la recherche lira ce formulaire de consentement avec vous et pourra répondre à toutes vos questions. Le Comité d'éthique de la recherche en sciences de la santé et sciences, de l'Université d'Ottawa, a révisé les composantes éthiques de cette étude et a conclu qu'elles sont conformes avec les normes nationales.

L'objectif est de recruter un total de 105 femmes dans la région de Gatineau-Ottawa, 35 femmes qui courent en moyenne un minimum de 10km par semaine et qui rapportent ressentir des fuites urinaires durant la course, 35 femmes qui courent en moyenne un minimum de 10km par semaine mais qui n'ont jamais eu de fuites urinaires à la course, ainsi que 35 femmes en bonne santé qui ne font pas d'activité physique régulièrement et qui ne rapportent pas de fuites urinaires. Vous avez été invitée à participer à cette étude puisque vous faites partie de l'une de ces trois catégories.

But de l'étude

Par l'entremise de cette étude, nous visons à mieux comprendre la contribution relative des muscles du plancher pelvien ainsi que des tissus conjonctifs aux fuites urinaires durant la course.

Cette étude comprend la complétion de sept questionnaires en ligne (approximativement 1 heure) et une évaluation en laboratoire d'une durée d'environ 2.5 heures.

Questionnaires

Si vous acceptez de participer, vous recevrez par courriel un hyperlien vous donnant accès à sept questionnaires en ligne. Vous pouvez demander de recevoir ces questionnaires par la poste ou par fax au lieu de les recevoir par courriel. Les questionnaires ne prendront pas plus d'une heure à compléter. Ces questionnaires vous poseront des questions à propos de (1) votre qualité de vie, (2) votre historique médical, (3) le fonctionnement de votre système intestinal, (4) le fonctionnement de votre système urinaire, (5) votre profil d'activité physique au cours de votre vie, et (6) les facteurs de risque pour l'exercice. Vous aurez besoin de remplir tous les questionnaires avant de vous présenter à la séance en laboratoire. Si vous remplissez les questionnaires en version papier, nous vous demanderons de les envoyer par la poste à l'équipe de recherche avant votre rendez-vous d'évaluation, car l'équipe de recherche doit évaluer vos réponses afin d'assurer votre admissibilité à participer avant que vous ne vous présentiez à la séance d'évaluation. Sur l'un des questionnaires, le Par-Q, si vous obtenez un score de plus de zéro, vous ne serez pas invitée à compléter l'évaluation en laboratoire car ce score nous indique que le protocole de course de cette étude vous mettrait à risque d'avoir des symptômes cardiaques. Sur le second questionnaire, le LEAF, si vous obtenez un score de plus de huit, vous ne serez pas invitée à compléter l'évaluation en laboratoire. Ceci nous indique que vous faites de l'activité physique au point où le système hormonal de votre corps n'est plus équilibré, et ceci pourrait influencer les résultats de cette étude. Si vous n'êtes pas invitée à participer à l'évaluation en laboratoire, vous allez être informée de la raison qui justifie cette décision. Si vous correspondez à nos critères d'éligibilité, vous serez invitée à vous présenter à l'évaluation en laboratoire.

L'évaluation en laboratoire

Cette séance aura lieu au Laboratoire de Mesure de la Fonction Motrice (MFM) à l'Université d'Ottawa au 200 rue Lees, pièce E155D. La rencontre sera d'une durée approximative de 2.5 heures.

Deux membres du personnel de recherche seront présents à cette rencontre, une assistante de recherche et une physiothérapeute chercheuse, Marie-Ève Bérubé. Mme Bérubé effectuera toutes les procédures de cette évaluation en laboratoire. Marie-Ève est physiothérapeute et membre de l'Ordre professionnel de la physiothérapie du Québec et est reconnue comme une physiothérapeute en rééducation périnéale et pelvienne. Mme Bérubé sera accompagnée d'une assistante de recherche qui l'aidera avec la préparation des instruments de recherche et qui sera responsable de l'opération des ordinateurs. Cette dernière n'effectuera aucune technique d'évaluation clinique.

1 heure avant l'heure prévue de votre rendez-vous au laboratoire, il vous sera demandé d'aller uriner et de vider votre vessie complètement. Par la suite, vous devrez immédiatement boire 350mL. S'il-vous-plaît, tentez de ne pas boire aucun thé/tisane, café ou boisson énergétique 3 heures avant votre participation à cette étude. Ceci pourrait vous donner une envie urgente d'uriner et pourrait interférer avec le protocole de cette étude. En laboratoire, Mme Bérubé mesurera votre taille, votre poids, votre tour de taille et votre tour de hanche. Par la suite, nous vous laisserons dans un endroit privé pour vous dévêtir à partir de la taille et nous vous donnerons une robe d'hôpital pour vous couvrir. Lorsque vous serez prête, vous inviterez Mme Bérubé et l'assistante de recherche à retourner dans la salle d'évaluation. Vous vous positionnerez couchée sur le dos, avec un oreiller derrière la tête. Mme Bérubé fera un examen physique de routine en physiothérapie de vos muscles du plancher pelvien. Mme Bérubé évaluera votre capacité à ressentir le toucher léger à l'intérieur des cuisses afin d'assurer que vous n'avez aucun problème au niveau des nerfs qui fournissent les sensations au plancher pelvien. Un réflexe sera vérifié en faisant un léger étirement et tapotement de votre périnée. Par la suite, Mme Bérubé sentira votre musculature pelvienne à l'aide de 2 doigts insérés dans votre vagin qui seront couverts de gants de vinyle. En gardant les deux doigts insérés, il vous sera demandé de contracter vos muscles du plancher pelvien le plus fortement possible afin d'évaluer votre force musculaire, par la suite, nous vous demanderons de relâcher vos muscles pelviens pendant que Mme Bérubé appliquera un étirement léger à l'ouverture vaginale afin d'évaluer la flexibilité des muscles de votre plancher pelvien. Vous pourrez en tout temps lui demander d'arrêter ou de ralentir le test.

À ce point, il est possible que vous soyez retirée de l'étude si Mme Bérubé détermine que vous avez des sensations ou réflexes anormaux de votre plancher pelvien, ou si elle observe des variations anatomiques telles qu'une descente d'organe. Si votre participation est discontinuée, Mme Bérubé vous recommandera de consulter votre fournisseur de soins de santé habituel (médecin ou infirmier(ère)-praticien(ne)) et vous expliquera les raisons de votre retrait. Elle répondra à vos questions ou inquiétudes avant que l'évaluation soit complétée. Si vous êtes retirée de l'étude, nous vous demanderons votre permission pour garder votre nom et vos coordonnées dans nos dossiers afin de vous joindre pour vous demander pour confirmer votre intérêt à participer à de futures études dans notre laboratoire. Si vous n'acceptez pas que l'on garde ces informations, nous les enlèverons de nos dossiers de façon permanente et nous ne prendrons plus contact avec vous.

Si vous êtes toujours éligible à poursuivre, Mme Bérubé évaluera la force de vos muscles pelviens ainsi que la flexibilité de ces muscles en utilisant un appareil nommé un dynamomètre. Ceci ressemble à un examen de routine PAP, à l'exception que vous serez en position debout et serez supportée par la table d'examen. Les branches du dynamomètre seront couvertes d'un condom et nous vous demanderons de l'insérer et de le guider à l'intérieur de votre vagin. Mme Bérubé s'assurera du positionnement adéquat de l'appareil et le tiendra en place à une angulation qui est confortable. Les branches du dynamomètre vont ouvrir lentement et nous vous demanderons de faire 3 contractions maximales de vos muscles du plancher pelvien, comme si vous vouliez tenter de fermer les branches du dynamomètre ensemble. Ces dernières se refermeront et l'appareil sera retiré de votre vagin.

Par la suite, nous vous demanderons de vous coucher sur le lit d'examen. Vos jambes seront supportées et votre tronc sera incliné. Deux électrodes collantes seront collées sur votre peau dans

la région près de l'anus et une autre sera collée près de votre hanche. Similairement, nous vous demanderons de guider le dynamomètre à l'intérieur de votre vagin. À ce moment-ci, nous vous demanderons de garder vos muscles du plancher pelvien complètement relâchés pendant que les branches du dynamomètre ouvrent pour 5 secondes afin d'étirer vos muscles du plancher pelvien, et qu'elles se referment. Cet étirement sera complété 3 fois et le dynamomètre sera retiré de votre vagin. À des fins de sécurité, le dynamomètre est opéré à partir d'une batterie et a des limites qui sont fixées de façon à ce que les branches du dynamomètre ne puissent pas étirer de façon excessive vos tissus ou les pincer. De plus, nous vous donnerons un bouton de sécurité qui ferme automatiquement le dynamomètre et le système entier. Vous aurez ce bouton entre vos mains durant tout le test et nous allons nous assurer que vous êtes en mesure de l'utiliser.

Par la suite, Mme Bérubé mesurera le montant de liquide dans votre vessie en mettant un ultrason sur votre abdomen, similaire à l'ultrason qui est utilisé pour évaluer un bébé lorsqu'une femme est enceinte. L'ultrason est utilisé afin de confirmer que votre vessie contient un montant d'urine modéré. Si votre vessie n'est pas pleine, nous vous demanderons de boire une petite quantité d'eau (1/2 tasse) et d'attendre 20 minutes. Si votre vessie est trop pleine, nous vous demanderons d'aller à la toilette afin d'uriner une petite quantité d'urine. Lorsque votre vessie aura le bon montant d'urine, l'imagerie par ultrason de votre périnée débutera pendant que vous êtes en position debout. Mme Bérubé vous fournira des instructions claires et vous aidera à pratiquer toutes les tâches avant que les images d'ultrason soient prises. L'évaluation par ultrason implique l'application d'une sonde recouverte d'un condom et de gel sur les parties génitales. La sonde n'est pas insérée à l'intérieur du vagin, elle repose sur la peau. Des photos seront prises en position debout lorsque vous contractez vos muscles du plancher pelvien et lorsque vous poussez vos muscles vers le bas. Chaque tâche sera répétée trois fois. Ceci conclura l'évaluation avant la course. Vous pourrez en tout temps demander d'arrêter ou de ralentir le test.

Pour la préparation à l'évaluation de votre course, vous recevrez des instructions afin d'insérer un petit appareil qui mesure la pression dans votre vagin en position couchée ou debout selon votre préférence. Cet appareil est similaire à un tampon auquel des fils sont attachés. Mme Bérubé fera une vérification afin de s'assurer que l'appareil est inséré correctement et il vous sera demandé de mettre votre petite culotte, à laquelle sera collée une serviette d'incontinence. Vous allez par la suite mettre une paire de cuissard (lycra) pour la course qui permettra de tenir les fils de l'appareil mesurant la pression en place. Avec l'appareil à l'intérieur de votre vagin, vous allez vous étendre sur le lit d'examen pour 10 minutes afin que ce dernier ait la même température que celle de votre corps. Vous allez vous lever et faire une série de toux, de poussées vers le bas, de sauts ainsi que soulever des poids de 15 livres dans chaque main. Ceci permettra de s'assurer que l'appareil ne sortira pas de votre vagin durant la course. Après ces tâches, Mme Bérubé vérifiera si l'appareil a descendu. Si ce dernier a descendu, il sera réinséré et le processus sera répété. Si l'appareil descend encore, il sera retiré et la pression dans votre abdomen ne sera pas enregistrée durant la course. Vous ne serez pas retirée de l'étude.

Finalement, un dernier petit appareil nommé un accéléromètre sera attaché avec du ruban adhésif sur votre peau du côté gauche de votre bassin et deux semelles très minces seront collées dans vos souliers. Vous devrez aussi porter une montre de type Fitbit sur votre poignet. Avant de courir sur le tapis roulant, vous devrez marcher 5 fois et courir 5 fois sur une rampe qui sera au sol. Par la suite, vous irez sur le tapis roulant et vous recevrez des instructions sur comment augmenter la vitesse du tapis roulant de la marche à une course à la vitesse de 7km/h. À cette vitesse, vous

courrez pour 2 minutes. Par la suite, vous augmenterez la vitesse du tapis à 10km/h, courir pour 2 minutes et finalement l'augmenter à 15km/h pour courir 2 minutes. À ce point-ci, il vous sera demandé d'augmenter ou de diminuer la vitesse du tapis roulant afin que vous puissiez courir à une vitesse que vous jugez modérément difficile. Deux petites vidéos seront prises lorsque vous courrez à cette vitesse pour 30 minutes. Par la suite, vous diminuerez la vitesse à 10km/h pour 30 secondes et à 7km/h pour 30 secondes. Si vous vous sentez à bout de souffle ou si vous êtes inconfortable durant la course, vous êtes autorisée à ralentir ou à marcher pour 1 minute avant de reprendre votre vitesse de course ou de la reprendre à une vitesse moindre. Pendant que vous courrez, il vous sera demandé de mentionner tous les épisodes de fuites urinaires. De l'eau sera fournie si vous en sentez le besoin.

Immédiatement après la course (30 secondes), la serviette d'incontinence sera retirée de votre petite culotte et sera pesée, l'appareil intra-vaginal, l'accéléromètre et les semelles seront retirés également. Les protocoles d'imagerie par ultrason et de dynamométrie seront répétés dans le même ordre. Vous devrez également indiquer votre niveau de fatigue en utilisant une échelle de fatigue qui vous sera fournie.

Risques

Même si vous êtes enceinte et vous n'êtes pas au courant, aucune des techniques utilisées dans cette étude met à risque le développement de votre fœtus. Ceci étant dit, s'il-vous-plaît ne pas vous porter volontaire et participer si vous savez que vous êtes enceinte.

Il n'y a aucun risque connu associé avec les procédures d'évaluation utilisées dans cette étude. Le dynamomètre utilisé pour mesurer la force de vos muscles du plancher pelvien ne devrait pas causer d'inconfort à tout moment. Vous pourriez ressentir un étirement lorsque l'appareil ouvre et qu'il applique un étirement à vos tissus pelviens, par contre, ceci devrait être ressenti comme n'importe quel étirement qu'on applique aux autres muscles de votre corps. Tel que noté, vous aurez accès à un bouton de sécurité qui permet de fermer l'appareil à tout moment si vous n'êtes pas à l'aise ou si vous êtes inconfortable.

L'imagerie par ultrason ne présente pas d'effet nuisible aux humains. Afin de minimiser le risque d'infection, les sondes sont recouvertes d'un condom lors de leur utilisation, et entre participantes, les sondes seront aseptisées selon les normes de contrôle d'infections fournies par le fabricant. Les branches du dynamomètre sont utilisées une seule fois et sont jetées par la suite. Elles sont imprimées dans un plastique biocompatible (PLA) et sont recouvertes de condoms sans latex afin de minimiser le risque d'infection ou de réaction. Le petit appareil qui mesure la pression est utilisé qu'une seule fois afin de minimiser le risque d'infection ou de réaction.

Durant la tâche où l'on vous demandera de pousser vos muscles du plancher pelvien, vous pourriez ressentir un peu d'étourdissement. Si vous vous sentez étourdie ou avez besoin d'une pause, mentionnez-le à l'équipe de recherche. Vous aurez des pauses suffisantes entre les répétitions afin d'éviter de causer cette sensation.

En cas de blessure improbable liée à cette étude (par exemple, vous trébuchez, glissez ou tombez lors de la séance d'évaluation en laboratoire), nous vous recommanderons de consulter votre

fournisseur habituel de soins de santé afin que vous receviez les soins et traitements médicaux appropriés fournis par votre régime provincial d'assurance-maladie. Si des soins urgents sont nécessaires, nous aviserons le service de la protection de l'Université d'Ottawa et le personnel de recherche vous accompagnera à l'urgence de l'hôpital d'Ottawa pour que vous puissiez recevoir des soins. En participant à cette étude, vous ne renoncez à aucun de vos droits légaux. La physiothérapeute chercheuse et étudiante graduée Mme Bérubé est spécifiquement entraînée afin de réaliser l'évaluation de vos muscles pelviens qui sera utilisée dans cette étude.

Bienfaits

En participant à cette étude, vous serez informée de l'état de la musculature de votre plancher pelvien. Vous apprendrez comment faire une bonne contraction de vos muscles du plancher pelvien et recevrez de la rétroaction de la part du physiothérapeute chercheur.

Compensation

Vous ne serez pas payée pour participer à cette étude.

Retrait de l'étude

Vous avez le droit de retirer votre participation dans cette étude en tout temps sans fournir de raison. Si vous choisissez de vous retirer de l'étude, toutes les données que vous nous avez fournies seront détruites, à moins que vous nous donniez la permission de les retenir et de les utiliser.

Confidentialité

Aucune publication ou présentation résultant de cette étude ne pourra servir à vous identifier. Aucune information vous identifiant ne quittera l'Université d'Ottawa. Un seul fichier contiendra votre nom et votre numéro de participant, et il sera protégé par un mot de passe et sauvegardé dans un ordinateur crypté situé au Laboratoire de Mesure de la Fonction Motrice. Ce fichier ne sera accédé que par la Dre McLean et son personnel à l'Université d'Ottawa uniquement. Tous les dossiers électroniques seront sauvegardés à l'Université d'Ottawa dans une base de données sécurisée et seront protégés par un mot de passe d'utilisateur qui ne sera accessible que par la Dre McLean et son personnel à l'Université d'Ottawa. Tout le personnel du laboratoire a reçu des instructions en lien avec les procédures appropriées afin de protéger votre intimité et confidentialité. Ces derniers ont également signé des actes de confidentialité.

Tous les dossiers papiers seront conservés dans un classeur barré au Laboratoire de Mesure de la Fonction Motrice, dont l'accès est restreint. Tous les dossiers seront conservés pour une période de 10 années après la date de clôture de l'étude. À la fin de la période de rétention, tous les dossiers papiers seront déchiquetés ou jetés aux rebuts confidentiels, et les fichiers électroniques seront supprimés de façon permanente.

Droits des participantes

Votre participation à l'étude est volontaire. Vous êtes libre de choisir de refuser de répondre à certaines questions. Vous êtes aussi libre de choisir ou de refuser de vous soumettre aux tests, sans avoir à donner une raison. Les chercheurs peuvent vous retirer de l'étude à tout moment pour des raisons scientifiques. Dans ce cas, l'équipe vous donnera une raison claire et valable

pour le faire. Vous avez aussi le droit de recevoir une copie des formulaires de l'étude contenant vos informations personnelles.

En tant que participante à l'étude, vous avez le droit à un environnement dans lequel vous vous sentez à l'aise. Nous avons fait en sorte qu'une troisième personne (assistante de recherche femme) soit présente dans la salle d'évaluation pendant toutes les procédures d'évaluation. Si cela vous met plus confortable, vous pourrez aussi amener un(e) ami(e) ou un membre de votre famille avec vous et demander que cette personne soit présente dans la salle.

À tout moment, si vous avez d'autres questions ou des difficultés, vous pouvez joindre les chercheurs responsables de l'étude :

Linda McLean, PhD,

Marie-Ève Bérubé, PT, PhD candidate

ou bien les assistants de recherche au Laboratoire de Mesure de la Fonction motrice, au

Si vous avez des questions au sujet de l'étude ou si vous croyez avoir subi une blessure reliée à cette recherche, veuillez joindre Dre Linda McLean au 613-562-5800 poste 2544 dès que possible.

Le Comité d'Éthique de la Recherche en Sciences de la Santé et Sciences de l'Université d'Ottawa a révisé ce protocole et il a déterminé que ce dernier se conforme aux normes éthiques des études qui comportent la participation d'humains à l'Université d'Ottawa. Si vous avez des questions au sujet de vos droits en tant que participant humain, vous pouvez contacter le Responsable d'Éthique en Recherche à l'Université d'Ottawa au 613-562-5387 ou à ethics@uottawa.ca.

Appendix D: Consent to participate in research (English)



Version 1 – 31/05/2018

Consent to Participate in Research

Title of Study: Mechanisms underlying running-induced urinary incontinence in women

I understand that I am being asked to participate in a research study and that my participation is voluntary. This study protocol has been explained to me by Ms. Marie-Eve Bérubé, PT, PhD candidate.

I have read this 6 page Participant Information Sheet and Consent Form or have had this document read to me. All my questions have been answered to my satisfaction. If I decide at a later stage in the study that I would like to withdraw my consent, I may do so at any time.

I voluntarily agree to participate in this study.

A copy of the Participant Information Sheet and the signed Consent Form will be provided to me for my records.

Signatures

Participant's Name (Please Print)

Participant's Signature

Date

I grant permission for video recordings of my running to be used in presentations, conferences, or publications. I understand that all videos will be anonymized such that it is not possible to identify me.

Yes ☐

No ☐

Participant's Initials: _____

Investigator Statement (or Person Explaining the Consent)

I have carefully explained to the research participant the nature of the above research study. To the best of my knowledge, the research participant signing this consent form understands the nature, demands, risks and benefits involved in participating in this study. I acknowledge my responsibility for the care and well-being of the above research participant, to respect the rights and wishes of the research participant, and to conduct the study according to applicable Good Clinical Practice guidelines and regulations.

Name of Investigator/Delegate (Please Print)

Signature of Investigator/Delegate

Date

Appendix E: Consent to participate in research (French)



Version 1 -31/05/2018

Formulaire de consentement

Titre de l'étude: Mécanismes sous-jacents à l'incontinence urinaire durant la course chez les femmes

Je comprends que je suis invitée à participer à une étude et que ma participation est volontaire. Le protocole de cette étude m'a été expliqué par Mme Marie-Ève Bérubé, PT, candidate au doctorat.

J'ai lu ou bien on m'a lu les six pages de la Lettre d'Information et ce Formulaire de Consentement. Toutes mes questions ont été répondues à ma satisfaction. Je pourrai retirer mon consentement à participer à cette recherche à tout moment au cours de l'étude.

J'accepte volontairement de participer à cette étude.

Une copie de cette Lettre d'information et du Formulaire de Consentement signé me sera fournie pour mes dossiers.

Signatures

Nom de la participante (en lettres moulées)

Signature de la participante

Date

Je donne ma permission de faire l'enregistrement vidéo de ma course qui sera utilisé dans des présentations, des conférences ou des publications. Je comprends que toutes les vidéos seront anonymes afin qu'il soit impossible de m'identifier.

Oui ☐

Non ☐

Initiales: _____

Déclaration de l'investigateur (ou de la personne expliquant le consentement)

J'ai expliqué soigneusement à la participante la nature de ce projet de recherche pour l'étude susmentionnée. Pour autant que je sache, la participante apposant sa signature à ce consentement reconnaît la nature, les exigences, les risques et les avantages que comporte sa participation à l'étude. Je reconnais ma responsabilité envers le soin et le bien-être de la participante susmentionnée, le respect des droits et des désirs de cette dernière, et le déroulement de cette étude, conformément aux directives et aux règlements relatifs à la bonne pratique clinique.

Nom de la chercheuse ou de son délégué
(en lettres moulées)

Signature de la chercheuse ou de son délégué

Date

Appendix F: COVID-19 Screening, consent and modifications

COVID-19

Please complete the following questions before beginning your work today.

Name: _____
 Date: _____ Time: _____

Do you have any of the following new or worsening symptoms?

Yes ☐
No ☐

Fever/Chills

Yes ☐
No ☐

Cough

Yes ☐
No ☐

Difficulty breathing/
Shortness of breath

Yes ☐
No ☐

Sore throat/
Difficulty swallowing

Yes ☐
No ☐

Runny nose
(unrelated to
seasonal allergies)

Yes ☐
No ☐

Loss of taste
or smell

Yes ☐
No ☐

Not feeling well,
headache, unexplained
tiredness and muscle aches

Yes ☐
No ☐

Nausea, vomiting,
diarrhea,
abdominal pain

In the last 14 days, have you had close physical contact with a person who:

- Yes ☐ • was sick with a respiratory illness (had a new or worsening cough, fever or difficulty breathing)?
- No ☐ • has returned from travel outside of Canada in the last 14 days?
- No ☐ • was a confirmed or probable case of COVID-19?

Yes ☐
No ☐

In the last 14 days, have you travelled outside of Canada?

Yes ☐
No ☐

If you answered **YES** to any of these questions, **please return home and self-isolate**. Visit [OttawaPublicHealth.ca/COVIDCentre](https://ottawapublichealth.ca/COVIDCentre) for more information about getting tested.

If you are feeling unwell, contact your health care provider or call **Telehealth Ontario** at **1-866-797-0000** to speak to a registered nurse.

Adapted with permission from Toronto Public Health

17/06/2020

OttawaPublicHealth.ca/Coronavirus

Public Health
Santé publique



COVID-19

Veuillez répondre aux questions suivantes avant de commencer à travailler aujourd'hui

Nom : _____

Date : _____ Heure : _____

Présentez-vous l'un de ces nouveaux symptômes ou une aggravation de ceux-ci?



Fièvre / frissons



Toux



**Essoufflement /
difficulté à respirer**



**Mal de gorge /
Difficulté à avaler**



**Écoulement nasal
(sans lien avec les
allergies saisonnières)**



**Perte du sens du goût
ou de l'odorat**



**Malaise / mal de tête /
fatigue inexpliquée
et douleurs musculaires**



**Nausée / vomissement /
diarrhée /
douleur abdominale**



Oui ☐
Non ☐

Au cours des 14 derniers jours, avez-vous été en contact physique proche avec une personne qui :

- avait une maladie respiratoire (présentait une nouvelle toux ou une aggravation de la toux, de la fièvre ou des difficultés respiratoires)?
- est revenue d'un séjour à l'extérieur du Canada au cours des derniers 14 jours?
- était un cas confirmé ou présumé de la COVID-19?



Oui ☐
Non ☐

Au cours des 14 derniers jours, avez-vous voyagé à l'extérieur du Canada?



Si vous avez répondu **OUI** à l'une de ces questions, **veuillez rentrer à la maison ou y rester, puis vous isoler**. Rendez-vous sur [SantePubliqueOttawa.ca/CliniqueCOVID](https://santepubliqueottawa.ca/CliniqueCOVID) pour en savoir plus sur le dépistage.

Si vous ne vous sentez pas bien, appelez votre fournisseur de soins de santé ou encore **Télésanté Ontario** au **1-866-797-0000** pour parler à une infirmière autorisée.

Adapté avec permission de Toronto Public Health

17/06/2020

[SantePubliqueOttawa.ca/CoronavirusFR](https://santepubliqueottawa.ca/CoronavirusFR)

 Santé publique
Public Health

uOttawa Consent Information Addendum- COVID-19 Risks

Principal Investigator: Dr. Linda McLean , Rehabilitation Sciences, Engineering,

Study Title: Mechanisms underlying running-induced urinary incontinence in women

Please read the following statements carefully and feel free to ask questions if anything seems unclear.

We are putting in place safety precautions to reduce exposure to COVID-19, but the risk of exposure can still exist. COVID-19 can result in severe illness, medical expenses, and loss of income and in some cases, death.

If you are considered vulnerable to the effects of COVID-19 (e.g., an older adult; underlying medical conditions or a compromised immune system), please discuss your participation with the research team before consenting to participate.

If you are feeling unwell or experiencing any potential COVID-19 symptoms leading up to the research session, please stay home and notify the research team that you cannot attend. Should you experience symptoms in days following the session, please also notify the research team.

Potential COVID-19 symptoms include: new or worsening cough, shortness of breath or difficulty breathing, temperature equal to or over 38C (100.4F), feeling feverish, chills, fatigue or weakness, muscle or body aches, new loss of smell or taste, headache, gastrointestinal symptoms (abdominal pain, diarrhea, vomiting), or feeling very unwell.

To reduce the possibility of COVID-19, we have implemented the following safety procedures

- Regular handwashing
- Using hand sanitizer when handwashing is not possible
- Wearing of face masks/face coverings
- Physical distancing (as recommended by the local health authority)
- Limiting shared material and documents (pens, paper)
- Sanitizing surfaces and shared equipment
- Waiting 60 minutes between each session
- Using face shields or goggles
- Using lab coats
- Collecting personal contact information for contact-tracing purposes.

Please advise a researcher if you believe a safety measure is not being taken, or that your safety is at risk.

Considerations for the Participant:

We ask that you:

- Wear a mask or face covering. Masks will be provided by the researcher if you do not have one. If you feel that you are unable to wear a mask, discuss your participation with the research team.
- Complete a [screening assessment](#) before each research session.
- Wash or sanitize your hands upon arrival. Hand sanitizer will be provided or a washing station will be available.
- Maintain physical distancing to the extent possible during the in-person research activities.

We ask that you follow the health-related directives above for your safety and the safety of the researchers.

Information for Contact Tracing

We are collecting personal contact information for contact-tracing purposes, in the event that you may have been exposed to COVID-19 at the research site.

Your name and contact information:

- Will not be stored with the research data
- Will always be securely stored
- Will only be used if requested by Public Health authorities for COVID-19 contact tracing purposes
- Will be held only for the time required by Public Health authorities

Right to Withdraw

You are under no obligation to participate. You can stop participating or withdraw from the study at any time by notifying the researcher using the contact information above.

Thank you for your interest and participation.

Information for Contact Tracing (to be kept separately from research documents)

This information:

- will not be stored with the study data;
- will always be securely stored;
- will be used only if requested by public health to provide this information for COVID-19 contact tracing purposes; and
- will be held only for the time required by public health authorities

Participant

Name (please print): _____ (required)

Signature: _____ (required)

Phone: _____ (required)

Email: _____ (optional)

Date: _____ (required)

Researcher

Name (please print): Marie-Ève Bérubé

Advenant au formulaire de consentement pour la COVID-19

Chercheuse ou chercheur principal : Dr. Linda McLean, Sciences de la Réadaptation, Génie,

Titre du projet : Mécanismes sous-jacents à l'incontinence urinaire durant la course chez les femmes

Veuillez lire attentivement les informations contenues dans ce document et veuillez poser toute question de clarification.

Nous mettons en place des mesures de sécurité pour réduire l'exposition à la COVID-19, mais le risque d'exposition peut toujours exister. La COVID-19 peut entraîner une maladie grave, des frais médicaux, une perte de revenu et, dans certains cas, la mort.

Si vous considérez que vous appartenez à un groupe vulnérable par rapport à la COVID-19 (p. ex. une personne âgée, des conditions médicales sous-jacentes, un système immunitaire affaibli), veuillez discuter de votre participation avec l'équipe de recherche avant d'accepter.

Si, avant la session, vous ne vous sentez pas bien ou si vous présentez des symptômes potentiels de la COVID-19, restez à la maison et informez l'équipe de recherche que vous ne pouvez pas vous présenter. Veuillez également informer l'équipe de recherche si vous avez des symptômes dans les jours qui suivent votre participation.

Les symptômes de la COVID-19 peuvent inclure : l'apparition ou l'aggravation d'une toux, l'essoufflement ou des difficultés respiratoires, une température égale ou supérieure à 38°C, une sensation de fièvre, des frissons, de la fatigue ou des faiblesses, des douleurs musculaires ou des courbatures, la perte de l'odorat ou du goût, le mal de tête, des symptômes gastro-intestinaux (douleur abdominale, diarrhée, vomissements), ou des maux intenses.

Afin de réduire le risque de contracter la COVID-19, nous avons mis en place les mesures suivantes :

- Lavage régulier des mains
- Utilisation d'un désinfectant à mains s'il est impossible de se laver les mains
- Port d'un masque/couvre-visage
- Distanciation physique (selon les recommandations de la Santé publique locale)
- Limitation du partage de matériel et de documents (stylos, documents papier)
- Désinfection des surfaces et de l'équipement
- Période tampon de 60 minutes entre chaque séance
- Utilisation d'écrans faciaux ou de lunettes de protection
- Port du sarrau
- Obtention de coordonnées personnelles pour fins de recherche de contacts

Veuillez aviser un chercheur si vous croyez que les mesures appropriées ne sont pas en place, ou si vous croyez que vous n'êtes pas en sécurité.

Considérations pour le participant :

Nous vous demandons de :

- Veiller à porter un masque ou un couvre-visage. Si vous n'avez pas un masque, le chercheur vous en fournira un. Si vous croyez que vous ne pouvez pas porter de masque, veuillez discuter de votre participation avec l'équipe de recherche.
- Remplir un [questionnaire d'évaluation de la santé](#) avant chaque visite.
- Laver ou désinfecter vos mains à l'arrivée. Un désinfectant pour les mains sera fourni ou une station de lavage sera disponible.
- Maintenir la distanciation physique dans la mesure du possible pendant les activités de recherche en personne.

Nous vous demandons de suivre ces directives liées à la santé pour votre sécurité et celle des chercheurs.

Information pour recherche de contacts

Nous recueillons des informations personnelles pour des fins de recherche de contacts, dans l'éventualité où vous aurez été exposé au virus de la COVID-19 sur le lieu de la recherche.

Votre nom et vos coordonnées :

- Ne seront pas conservés avec les données de recherche
- Seront conservés de façon sécuritaire
- Seront partagés seulement s'il y a une demande de la part de la Santé publique, pour des fins de recherche de contacts
- Seront détruits dès que ceci est permis par la Santé publique.

Droit de se retirer de la recherche

Vous n'êtes pas obligé de participer à cette recherche. À tout moment, vous pouvez cesser de participer ou vous retirer de l'étude en informant le chercheur (coordonnées ci-dessus).

Merci pour votre intérêt et votre participation.

Information pour recherche de contacts [Instructions : détacher cette section et la conserver séparée des données de recherche]

Cette information :

- Sera conservée de façon sécuritaire
- Ne sera pas conservée avec les données de recherche
- Sera partagée seulement s'il y a une demande de la part de la santé publique, pour des fins de recherche de contacts
- Sera détruite dès que la santé publique le permet

Participant

Nom (écrire en lettres moulées) : _____

Numéro de téléphone : _____

Courriel : _____

Date : _____

Chercheur

Nom (écrire en lettres moulées) : Marie-Ève Bérubé

Step by step protocol for the treadmill running aspect of this study

- Once the participant is ready to start the running protocol on the treadmill in A122, they will go on the treadmill with their mask on.
- The researcher, who will still be wearing PPE, will instruct the participant on how to safely use the treadmill; change the speeds, and will ensure that the participant is wearing a safety clip.
- The treadmill will be surrounded by 7 feet plexiglass panels on each side and in the front as shown in the following image.



- Once the participant is ready to start running, they will disinfect their hands and remove their mask and put it on the treadmill.
- The researcher will always remain 3 m away and, other than when acquiring the video clips, will be behind the participant during the running protocol; unless there is an emergency that requires the researcher to intervene.
- Once the running protocol is over (37 minutes), the participant will be asked to disinfect their hands with the sanitizer provided, and put their mask back on.
- Both the researcher and the participant will go back into the assessment room A122C to evaluate the pelvic floor muscles.
- The door in the room where the running protocol took place will be closed before exiting the room and a sign will be posted to indicate that the room must remain vacant for at least 40 minutes.
- The researcher will complete the research protocol in A122C (20 minutes) and will start the disinfecting process in the assessment room of all the equipment in A122C and A122B (20 minutes). Once this is done, the researcher, still wearing PPE, will go back into the room A122 with the treadmill to start the disinfection protocol. The plexiglass will be sprayed using disinfectant according to the manufacturer guidelines and entire treadmill (belt, handles, panel) will be disinfected using peroxide hydrogen wipes.
- Once cleaning is complete, the door to the room will remain closed and the room will remain vacant until the next participant, which will be, at a minimum, the following day.

Appendix G: Recruitment flyers



Female Runners Wanted

Many women have problems with urine leakage while exercising. The Motor Function Measurement Lab at the University of Ottawa is currently recruiting female runners. Through this study, we aim to determine how the pelvic floor muscles respond to stresses imposed by running. Your participation in this study entails the completion of questionnaires (1 hour) and an in-lab assessment of your pelvic floor and running mechanics using custom intra-vaginal devices and ultrasound imaging at the University of Ottawa (2.5 hours).

You can participate if you:

- Are a cis-female older than 18 years old
- Have run at least 10 km / week for at least one year
- Participation is wanted whether or not you have problems with urine leakage when you run

You cannot participate if you have:

- A history of major surgery to your bladder or uterus
- A neurological condition such as stroke, multiple sclerosis, etc.
- A pelvic organ prolapse
- Delivered a baby during the last year or are pregnant
- Pain with regular gynecologic examinations

Contact information

Marie-Ève Bérubé
PhD candidate
Physiotherapist

Benefits: You will learn about urine leakage when you run and you will be taught how to perform a proper pelvic floor muscle contraction by a pelvic health physiotherapist.

****First come first served****

Principal investigator: Dr. Linda. McLean, PhD, School of Rehabilitation Science, University of Ottawa

Version 3 - January 1, 2019

Coureuses Recherchées

Plusieurs femmes ont des fuites urinaires lorsqu'elles font de l'exercice. Le Laboratoire de Mesure de la Fonction Motrice de l'Université d'Ottawa recrute présentement des adeptes de la course. Nous visons à déterminer comment les muscles du plancher pelvien réagissent au stress induit par la course. Votre participation comprend la complétion de questionnaires (1 heure) et une évaluation en laboratoire à l'Université d'Ottawa (2.5 heures) de vos muscles du plancher pelvien et de votre course en utilisant des appareils intra-vaginaux et l'imagerie par ultrasons.

Vous pouvez participer si vous:

- Êtes une cis-femme de plus de 18 ans
- Vous courez au minimum 10 km par semaine au cours de la dernière année
- Votre participation est voulue si vous avez des fuites urinaires ou non durant votre course

Vous ne pouvez pas participer si vous avez:

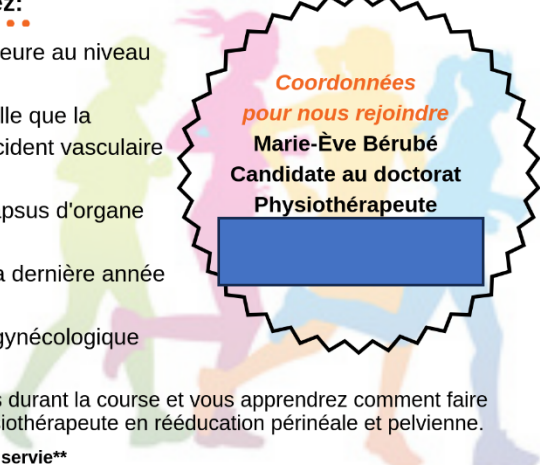
- Un historique de chirurgie majeure au niveau de la vessie ou l'utérus
- Une condition neurologique telle que la sclérose en plaques ou un accident vasculaire cérébral
- Une descente d'organe / prolapsus d'organe pelvien
- Accoucher d'un bébé durant la dernière année ou si vous êtes enceinte
- Douleur avec une évaluation gynécologique de routine

Bénéfices: Vous allez apprendre de l'information sur les fuites urinaires durant la course et vous apprendrez comment faire une contraction des muscles du plancher pelvien adéquate par une physiothérapeute en rééducation périnéale et pelvienne.

****Première arrivée, première servie****

Chercheuse principale: Dre. Linda. McLean, PhD, École des Sciences de la Réadaptation, Université d'Ottawa

Version 3 - 1 janvier 2019



**Coordonnées
pour nous rejoindre
Marie-Ève Bérubé
Candidate au doctorat
Physiothérapeute**

Appendix H: Telephone interview (English)

Version 3 – 17/06/2019

Telephone Information Sheet

Hello, my name is Marie-Eve Bérubé. I am a graduate student researcher completing my doctorate in Dr. Linda McLean's Motor Function Measurement Laboratory at the University of Ottawa.

Thank you for your interest in the study entitled, "Mechanisms underlying running-induced urinary incontinence in women".

I would like to tell you about the purpose of the study, as well as the details of what your participation would entail if you are eligible and choose to participate.

Is this a good time?

If she says no, "is there a convenient time for me to call you back?"

Great. If you are still interested after the description of the study, then I will ask you a number of questions to determine your eligibility for the study. This description and screening questionnaire could take about 20-30 minutes, and some of the questions are personal in nature. Is this a good time to complete the interview?

If she says no,

Can we schedule a time to do this that would be more convenient for you? And log appointment in laboratory calendar.

If she says yes,

OK good. Please interrupt me at any time if you have questions.

Many women leak urine while they run and this can lead to them abandoning running as a form of regular exercise. The purpose of this study is to investigate the mechanical causes of urine leakage in female runners, and to compare several of these measures between women who run and women who are less active. We will do this by evaluating structural and mechanical differences in the pelvic floor muscles and connective tissues recorded before a running task among women who run and report that they regularly leak urine, women who run and report never having leaked urine while running, and women who are less active. In the women who run regularly we will also measure differences induced after a single run of 30 minutes duration. During the run, we will also monitor abdominal pressure and forces exerted on women's bodies in order to determine whether these measures have an impact on the continence mechanism in women. For women who do not run regularly, they will not be asked to run as part of this study. The idea is that if we can determine factors that are associated with urine leakage, we can work on interventions to prevent it.

We will focus primarily on the pelvic floor muscles, as they have been implicated in urine leakage, particularly while women exercise, but their role is not well understood. To study pelvic floor muscle structure and function, we will use ultrasound imaging of the pelvic structures, and a special device that measures the strength and flexibility of these muscles.

Should you choose to participate, your participation in the study will involve completing a series of on-line questionnaires and attending a one-time session in the research laboratory.

Are you interested in hearing about the study procedures?

If she says yes, then the study procedures will be explained to her.

If she says no, ask if there is a better time to discuss the study further, and note this on the telephone log sheet. If the potential volunteer states she is not interested in participating, ask why and record her response on log at the end of this form. Offer to send the study information and consent form for her to read at her leisure, and to contact you if she later decides that she is interested.

This is what will happen if you choose to participate. Feel free to stop me at any time to ask questions or to discuss any procedure in more detail.

First, you will be sent a letter of information about the study as well as a link to seven on-line questionnaires to fill out. These questionnaires are all short, and will take about 5-10 minutes each to complete. Next, you will come into the research laboratory of Dr. Linda McLean at the Lees Avenue Campus of the University of Ottawa for a testing session. This will be done by me, and the session will last about two and a half hours for runners and one and a half hour for women who do not exercise. We can schedule this session during regular work hours, in the evening or on the week-end; whatever makes it easiest for you to attend.

When you first arrive at the laboratory for your scheduled assessment session, you will be asked to sign the study informed consent form. Before signing this form you should make sure that all of your questions and concerns have been adequately addressed. Once you complete the consent form, you will be taken to the examination room for a pelvic floor muscle assessment which will be performed by me. I am a licensed pelvic health physiotherapist in Québec, and am a graduate student research assistant at the University of Ottawa. I will be accompanied by another female student research assistant to help me collect and record data during the assessment.

Your height and weight will be measured and recorded. You will then be left alone in the room to remove your clothes from your waist down and to cover yourself with a hospital gown that will be provided to you. Once you are changed, you will invite me back into the room. I will perform an assessment of your pelvic floor muscles and will teach you how to perform a proper pelvic floor muscle contraction. To do this, I will insert two gloved fingers into your vagina to feel your pelvic floor muscles, and I will resist contraction of your muscles so that you can feel them better. I will provide feedback to you so that you will learn how to perform a proper contraction. I will also test your sensation and will feel for any irregularities. At this point, there is a small chance that I may inform you that you are no longer eligible, and if that is the case, I will let you know why. If you are eligible to continue, I will instruct you on how to insert a pelvic floor muscle

strength testing device into your vagina. This device measures how hard you can contract your pelvic floor muscles and how flexible your pelvic floor muscles are. The device is similar to the one used when you have a regular PAP test. This is a safe device that does not carry risk of injury to your muscles. However, you will have a safety switch placed in your hand and clicking the switch will stop the device in case you feel any discomfort. This part of the assessment will last approximately 20 minutes.

Next I will use ultrasound imaging to estimate how much urine is in your bladder. This will be similar to the ultrasound examination done to see the baby in a pregnant woman's belly. If your bladder volume is too low, you will be asked to drink a small amount of water and to wait 20 minutes; if your bladder is too full, you will be asked to void a small amount. When your bladder volume is in the range we are looking for, which will be moderately full, you will undergo ultrasound imaging of your pelvis while you are in a standing position. I will place the ultrasound imaging probe over your vulva. I will take ultrasound images of your pelvic floor while you stand in a comfortable position, while you contract your pelvic floor muscles and while you bear down. I will give you instruction to help you complete these tasks.

This completes the testing protocol if you are a less active woman and do not run. Would you consider yourself as a runner or a less active woman?

This completes the testing protocol for the sedentary women. Pick up below where indicated. For women who are runners, carry on with next paragraph.

For female runners, explain this part

You will next be instructed to insert a small sensor that is like a tampon with small wires, into your vagina. The wires will be attached to a small box that will be strapped to your waist. The sensor measures the pressure on your pelvic floor. This sensor can be inserted while you are lying down or standing, depending on your preference. I will check the device after you have inserted it to make sure that it is in a good position. If it is, I'll ask you to put on your underwear, into which we will stick an incontinence pad. You will then put on a pair of lycra running shorts to hold all wires in place. These will be provided by our laboratory. You will be asked to lie down for 10 minutes while the sensor warms up to your body temperature. You will then be instructed to stand up and perform coughs, bearing down maneuvers, jumps, and a lifting task with fifteen pounds in each hand. These tasks will be used to ensure that the sensor does not come out of your vagina when you move around, as this would mean that it is not positioned correctly. If the sensor does fall down, you will be asked to set it back in place and the process will be repeated. If the sensor still falls down, it will be removed and we will not record pressure while you run; you will not be withdrawn from the study.

Lastly, a small sensor called an "accelerometer" will be taped to the skin over your pelvis and thin shoe insoles will be placed into your shoes. We will also put a Fitbit on your wrist. You will then be ready to begin the running protocol. My research assistant will start the treadmill and will help you to increase the speed from a walk to a slow jog, which will reach a speed of 7km/h. At this speed, you will run for 2 minutes, then we will increase the treadmill speed to 10km/h, you will run at this speed for 2 min, and then we will repeat this at 15km/h after which you will increase

or decrease the speed to your usual, comfortable running pace. This should be a speed that you consider to be somewhat hard but sustainable for 30 minutes. If you feel short of breath or feel any discomfort, you may reduce the treadmill speed or walk for a minute before resuming the running pace. While running, we will also ask you to report each episode of urine leakage that you are aware of, if you have any. After running for 30 minutes at your selected pace, you will cool-down for 30 seconds at each of the two previous test speeds. During the running task, two short videos will be recorded using a camera.

Immediately following the running task, the incontinence pad will be removed and weighed. The intra-vaginal sensor, the shoe insoles and the small device taped on your hip will all be removed. You will have to rate your fatigue using a simple scale how exhausted you feel and the ultrasound and dynamometer tests will be repeated.

Restart here for sedentary women

All communications for this study will be conducted in English or French based on your choice, however some questionnaires have not been validated in French. If you have difficulty completing these questionnaires in English, I can help you with this during your laboratory assessment visit.

My apologies for such a long description of the study procedures but I want to ensure that you fully understand what you are being asked to agree to. Do you have any questions?

At this point, are you interested in seeing if you are eligible for participating in the study?

If no, thank them for their time, and ask them to feel free to call back if they change their mind. Offer to send the study information and consent form for them to review, and record the reason given for not wishing to continue.

If yes, ask about each of the following, based on cohort:

Now I am going to ask you some questions to see if you are eligible to participate in the study. If you do not understand the question, let me know and I will explain it in more detail.

Exclusion criteria for all female runners:

- How old are you? _____ (* not eligible if under 18)
- Are you pregnant? Y [1] N [0]
- Have you delivered a baby during the last year? Y [1] N [0]
- What is your height? _____
- What is your weight? _____
- Have you been told by a health provider that you are obese? (estimate BMI based on the information provided) Y [1] N [0]
Exclude if estimated BMI is greater than 35kg/m² or if participant reports being informed that she is obese. BMI will be confirmed at the laboratory session.
- Are you taking any medications for urinary incontinence? Y [1] N [0]
- Have you received any other medical treatments for bladder leakage? (such as hormone creams, collagen injections, laser therapy or other medical treatments) Y [1] N [0]
- Have you ever had a surgery for incontinence, pelvic organ prolapse or endometriosis? Y [1] N [0]
- Have you ever had any other gynecological surgery Y [1] N [0]
If yes, tell me which ones you have had.

Partial Hysterectomy	O 1	Ovariectomy	O 5
Complete hysterectomy	O 2	Colposuspension:	O 6
TVT	O 3	Others _____	O 7
Tubal Ligation	O 4	None _____	O 8

- Are you aware of having any neurological conditions such as multiple sclerosis, spinal cord injury, stroke, or Parkinson's disease? Y [1] N [0]
- Do you know of any conditions you have that might affect your skin or connective tissues, such as Marfan's syndrome or Ehlers-Danlos syndrome? Y [1] N [0]
- Do you have any metallic devices in your pelvis, not including an IUD? Y [1] N [0]
- Are you aware of any health problems that might place you at risk if you perform physical activity? Y [1] N [0]
- Do you have pain when you insert vaginal tampons or during sexual activity? Y [1] N [0]
- Do you experience pelvic pain? Y [1] N [0]
- Are you aware whether you have a pelvic organ descent? (prolapse) Y [1] N [0]
If yes, does it bulge out of your vagina if you strain? Y [1] N [0]

**** Women need to run at least 5 km in under 50 minutes (minimum pace of 6 km/h to ensure high impact), at least twice per week (to ensure adequate frequency), and who have done so for at least one year (to ensure adequate duration of exposure)*****

- What is your usual weekly total running distance? (must be >10km) _____
- How many times a week do you run? _____ (must be > 2x/week)
- How long does your usual run last? _____
- Are you able to run at least 5km under 50 minutes Y [1] N [0] (not eligible if no)

- For how long have you been running this distance on a weekly basis? (must be >1 year) _____
- For how many months/years have you been running? _____
- Can you sustain a comfortable running pace for 40 minutes without stopping? Y [1] N [0]
(not eligible if no)

Exclusion criteria for female runners who report urinary incontinence

- Do you experience urinary incontinence while running? Y [1] N [0]
How often has this occurred over the past month? (should be at least once per week)
 - Every run
 - Once a week
 - More than once a week
 - Once a month
 - 2-5 episodes a month
 - More than 5 episodes a month
 - Is this leakage preceded by a sudden need to go to the bathroom? (answer should be no)
Y [1] N [0]
 - Do you experience urine leakage during other activities? Y [1] N [0]
If yes, which one's
 - Cough
 - Sneeze
 - Laughing
 - Lifting
 - Other: _____
- How often has this occurred? (should be less than once a month)
- Every day
 - On a weekly basis
 - On a monthly basis
 - Occasionally: a few times during a year
 - Rarely: a few times during lifetime
 - Other: _____

Exclusion criteria for female runners who report no history of urinary incontinence

- Have you ever experienced urine leakage while running? (answer must be no) Y [1] N [0]

Exclusion criteria for sedentary women:

- How old are you? _____ (not eligible if under 18)
 - Do you do any physical activity other than your daily chores? Y [1] N [0]
If so, which physical activity do you do? _____
How often? _____
Did you previously perform regular physical activity? Y [1] N [0]

If so, which physical activity did you use to do? _____

How often? _____

- Are you pregnant? Y [1] N [0]
- Have you delivered a baby during the last year? Y [1] N [0]
- What is your height? _____
- What is your weight? _____
- Have you been told by a health provider that you are obese? Y [1] N [0] (estimate BMI based on the information provided). Exclude if estimated BMI is greater than 35kg/m² or if participant reports being informed that she is obese. BMI will be confirmed at the laboratory session.
- Have you ever had a surgery for incontinence, pelvic organ prolapse or endometriosis? Y [1] N [0]
- Have you ever had any other gynecological surgery Y [1] N [0]

If yes, which ones you have had.

Partial Hysterectomy	O 1	Ovariectomy	O 5
Complete hysterectomy	O 2	Colposuspension:	O 6
TVT	O 3	Others _____	O 7
Tubal Ligation	O 4	None	O 8

- Are you taking any medications for urine leakage? Y [1] N [0]
- Have you received any other medical treatments for urine leakage? (such as hormone creams, collagen injections, laser therapy or other medical treatments)
Y [1] N [0]
- Are you aware of having any neurological conditions such as multiple sclerosis, spinal cord injury, stroke, or Parkinson's disease? Y [1] N [0]
- Do you know of any conditions you have that might affect your skin or connective tissues, such as Marfan's syndrome or Ehlers-Danlos syndrome? Y [1] N [0]
- Do you have any metallic devices in your pelvis, not including an IUD? Y [1] N [0]
- Do you have pain when you insert vaginal tampons or during sexual activity? Y [1] N [0]
- Do you experience pelvic pain? Y [1] N [0]
- Are you aware whether you have a pelvic organ descent? (prolapse) Y [1] N [0]
If yes, does it bulge out of your vagina if you strain? Y [1] N [0]

Exclusion criteria for sedentary women who report urinary incontinence

- Do you experience urinary incontinence? Y [1] N [0]
How often has this occurred over the past month? (should be at least once per week)
 - Daily
 - Almost daily
 - Once a week
 - More than twice per week
 - Once a month or less

If yes, which activities cause urine leakage

- ☐ Cough
- ☐ Sneeze
- ☐ Laughing
- ☐ Lifting
- ☐ Other: _____

- Is this leakage preceded by a sudden need to go to the bathroom? (answer should be no)
Y [1] N [0]

Exclusion criteria for sedentary women who report no history of urinary incontinence

- Have you ever experienced urine leakage (answer must be no or not within the last year)
Y [1] N [0]
 - ☐ If yes, when was your last episode of urine leakage? _____

ELIGIBLE? Y [1] N [0]

If no:

Thank you for your interest and your time. Unfortunately, you are not eligible for this study (explain why they are not eligible). Are you willing to allow us to keep your name and contact information in order to contact you about future studies for which you may be eligible?

Consent? Y [1] N [0]

Do you have any questions? Again, thank you for your time and have a good day.

If yes:

Thank you for your interest and your time. According to the information you provided, you are eligible for this study. Are there any reasons you can foresee that may cause you to suffer emotional or psychological distress if you undergo the study procedures? Y [1] N [0]. If you are still interested, I will mail, fax or email you the letter of information and consent form, and the questionnaires. Could you confirm your contact information? (make sure they have appropriate contact information). Before we book the testing, I need to know when your last menstrual period started. We will try to book you right after your next menstrual period (determine which week). When would be the best time to schedule the testing during that week? (book testing). You will receive a reminder by email/phone call before the testing to remind you of the appointment and to give you details of where to go and what to bring. How do you want to be reminded of your appointment? (email, phone message).

If eligible runner, ask this question.

To determine your leg dominance for the testing, I need to know which foot you use to kick a ball? R [1] L [0]

Do you have any questions?

Again, thank you for your time and have a good day. Feel free to contact us if you need more information.

Telephone Screening Form

Name: _____

Date of screening: _____(yyyy-mm-dd)

Home #: () - (best time to call:) leave a message? Y N
 Cell #: () - (best time to call:) leave a message? Y N
 Work #: () - (best time to call:) leave a message? Y N

Mailing address OR fax # (only if necessary) to send the questionnaires and LOI before the in-lab assessment:

Email address: _____

Call or email Log:

<u>Date</u>	<u>Time</u>	<u>RA</u>	<u>Outcome</u>
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Notes:

Appendix I: Telephone interview (French)

Version 3 – 17/06/2019

Document Entrevue Téléphonique

Bonjour, mon nom est Marie-Ève Bérubé. Je suis une étudiante graduée et chercheuse complétant mon doctorat dans le laboratoire de Mesure de la Fonction Motrice dirigé par Dre Linda McLean à l'Université d'Ottawa.

Merci de votre intérêt pour l'étude nommée «Mécanismes sous-jacents à l'incontinence urinaire durant la course chez les femmes».

J'aimerais vous expliquer le but de cette étude ainsi que les détails de votre participation si vous êtes éligible et si vous choisissez de participer.

Est-ce un bon moment

Si elle dit non, «est-ce qu'il y aurait un meilleur moment pour vous afin que je puisse vous rappeler?»

Excellent. Si vous êtes encore intéressée après la description de l'étude, je vais vous poser quelques questions afin de déterminer si vous êtes éligible pour l'étude. Cette description et les questions de dépistage pourraient prendre environ 20-30 minutes, et plusieurs de ces questions sont de nature personnelle. Est-ce que c'est un moment approprié pour compléter l'entrevue?

Si elle dit non,

Est-ce qu'on peut planifier un autre moment qui serait plus approprié pour vous? Inscrire le rendez-vous dans le calendrier du laboratoire.

Si elle dit oui,

Ok parfait. N'hésitez pas à m'interrompre à tout moment si vous avez des questions.

Plusieurs femmes ont des fuites urinaires lorsqu'elles courent et ceci peut les mener à abandonner la course comme activité physique. Le but de cette étude est d'évaluer les causes mécaniques des fuites d'urine chez les coureuses, et de comparer ces mesures entre les femmes coureuses qui n'ont pas de fuites urinaires, ainsi que chez les femmes qui sont moins actives. Nous allons étudier cela en évaluant les structures et les différences mécaniques de vos muscles du plancher pelvien et des tissus conjonctifs avant et après la course chez les femmes avec et sans fuites urinaires, ainsi que chez les femmes moins actives. Chez les femmes qui courent régulièrement, nous allons aussi mesurer les différences provoquées par une course de 30 minutes. Durant la course, nous allons surveiller la pression à l'intérieur de l'abdomen ainsi que les forces qui sont appliquées sur le corps des femmes afin de déterminer si ces mesures ont un impact sur les mécanismes qui maintiennent la continence chez les femmes. Pour celles qui ne courent pas régulièrement, elles ne compléteront pas la portion de l'étude qui comprend l'évaluation de la course. L'idée est que si nous pouvons déterminer les facteurs qui sont associés avec les fuites urinaires, nous pourrions trouver des interventions afin de mieux prévenir ces dernières.

Notre attention sera portée principalement sur les muscles du plancher pelvien, étant donné que ces derniers sont impliqués dans les fuites urinaires, particulièrement lorsque les femmes font

de l'exercice physique. Afin d'étudier la structure et la fonction de ces muscles, nous utiliserons l'imagerie par ultrason des structures pelviennes ainsi qu'un appareil spécial qui mesure la force et la flexibilité de vos muscles.

Si vous décidez de participer, votre participation à cette étude requerra que vous complétiez une série de questionnaires en lignes et que vous vous présentiez à une session au laboratoire de recherche.

Êtes-vous intéressée à connaître les procédures de l'étude?

Si elle dit oui, les procédures du projet de recherche lui seront expliquées.

Si elle dit non, demandez s'il y a un meilleur temps afin de discuter davantage et notez sur le journal téléphonique. Si la volontaire potentielle mentionne qu'elle n'est pas intéressée à participer, lui demander pourquoi et inscrire sa réponse dans le document à la fin de ce formulaire. Offrez-lui de lui envoyer la lettre d'information de l'étude et le formulaire de consentement afin qu'elle puisse les lire à sa guise. Offrez-lui de nous contacter si elle décide subséquemment qu'elle est intéressée.

Voici ce qui se passera si vous choisissez de participer. Ne soyez pas gênée de m'interrompre à tout moment pour me poser vos questions ou pour discuter des procédures plus profondément.

Premièrement, la lettre d'information de l'étude vous sera envoyée ainsi que le lien pour les sept questionnaires à compléter. Ces questionnaires sont courts et prendront environ 5-10 minutes chaque à compléter. Par la suite, vous vous présenterez au laboratoire de recherche du Dre Linda McLean sur le campus de l'Université d'Ottawa, situé sur l'avenue Lees, pour les tests. Ces tests seront complétés par moi-même et seront d'une durée de 2h30 (ou 1h30 pour les femmes sédentaires). Nous pouvons prendre rendez-vous durant les heures régulières de travail, en soirée ou durant les fins de semaine; peu importe quand il sera le plus facile pour vous de vous déplacer.

Lorsque vous arriverez au laboratoire pour votre rendez-vous d'évaluation, nous vous demanderons de signer le formulaire de consentement de l'étude. Avant de signer ce formulaire, vous devez vous assurer que toutes vos questions et craintes ont été adressées adéquatement. Une fois le formulaire de consentement complété, vous serez dirigée vers la salle d'examen où l'examen des muscles de votre plancher pelvien sera réalisé par moi-même. Je suis une physiothérapeute en rééducation périnéale et pelvienne qui est enregistrée au sein de l'Ordre Professionnel de la Physiothérapie du Québec. Je serai accompagnée d'une autre étudiante chercheuse graduée afin de m'aider à faire la collecte des données durant l'évaluation.

Votre grandeur et votre poids seront mesurés et enregistrés. Vous allez par la suite être laissée seule dans la salle d'examen afin de retirer vos vêtements du bas de votre corps et de vous couvrir avec une robe d'hôpital et des draps qui vous seront fournis. Une fois prête, vous pourrez me réinviter dans la salle d'examen. Je ferai un examen de vos muscles du plancher pelvien et vous

enseignerai comment faire une contraction du plancher pelvien adéquate. Afin de faire cela, j'insérerai deux doigts recouverts de gants à l'intérieur de votre vagin afin de sentir vos muscles du plancher pelvien et de résister votre contraction des muscles afin de mieux les sentir. Je vous donnerai de la rétroaction afin que vous puissiez apprendre à faire une contraction adéquate. Je vérifierai également votre sensation et porterai une attention aux irrégularités. À ce point-ci, il y a une mince chance que je vous informe que vous n'êtes plus éligible. Si tel est le cas, je vous expliquerai la raison. Si vous êtes éligible pour continuer, je vous donnerai des instructions afin que vous puissiez insérer l'appareil qui mesure la force de vos muscles du plancher pelvien dans votre vagin. Cet appareil mesure la force avec laquelle vous pouvez contracter vos muscles du plancher pelvien et la flexibilité de ces derniers. L'appareil est similaire à celui qui serait utilisé pour un examen PAP régulier. Cet appareil est sécuritaire et ne porte aucun risque de blesser vos muscles. Par contre, nous vous donnerons un bouton de sécurité dans vos mains. Lorsqu'on appuie sur le bouton, ce dernier arrête immédiatement l'appareil au cas où vous ressentiez de l'inconfort. Cette partie de l'évaluation sera d'une durée d'environ 20 minutes.

Par la suite, j'utiliserai l'imagerie par ultrason afin d'avoir une estimation de la quantité d'urine dans votre vessie. Ceci est similaire aux examens avec ultrason qui sont utilisés pour voir le bébé dans le ventre d'une femme enceinte. Si la quantité d'urine est trop faible, nous allons vous demander de boire une petite quantité d'eau et d'attendre 20 minutes; si la vessie est trop pleine, nous vous demanderons d'aller uriner une petite quantité. Lorsque votre vessie aura la bonne quantité d'urine, donc que cette dernière est modérément remplie, nous allons débiter l'examen d'imagerie par ultrason de votre périnée en position debout. Je positionnerai la sonde sur votre vulve et prendrai des images de votre plancher pelvien pendant que vous êtes debout en position confortable durant la contraction de vos muscles du plancher pelvien ainsi que quand vous faites une poussée. Je vous donnerai les instructions nécessaires pour compléter ces tâches.

Ceci complète les procédures si vous êtes une femme moins active et que vous n'êtes pas une coureuse. Vous considérez-vous comme une coureuse ou une femme moins active?

Ceci complète les procédures d'évaluation pour les femmes sédentaires. Continuez la lecture là où indiqué. Pour les coureuses, poursuivre depuis le prochain paragraphe.

Pour les coureuses, expliquez cette partie

Par la suite, vous recevrez des instructions afin d'insérer un petit appareil qui ressemble à un tampon dans votre vagin. Ce dernier comprend des fils qui sortiront de votre vagin. Ces derniers seront attachés à une petite boîte qui sera attachée à votre taille. Cet appareil mesure la pression sur votre plancher pelvien. Ce dernier peut être inséré en position debout ou coucher selon votre préférence. Je vérifierai que l'appareil est bien inséré et qu'il est en bonne position. Si ce dernier est bien positionné, je vous demanderai de remettre votre petite culotte à laquelle nous collerons une serviette d'incontinence. Nous vous fournirons par la suite des pantalons de course en lycra afin de tenir tous les fils en place. Vous devrez alors vous coucher sur le lit d'examen pendant 10 minutes afin que l'appareil puisse se réchauffer à la même température que votre corps. Nous vous demanderons ensuite de vous lever debout et de faire des toux, des poussées de votre plancher pelvien, des sauts et de soulever 15 livres dans chaque main. Ces tâches ont pour but

de s'assurer que l'appareil ne descende pas dans le vagin pendant que vous êtes active; ceci nous indiquerait que l'appareil n'est pas bien positionné. Si l'appareil tombe ou sort du vagin, il sera repositionné et le processus sera répété. Si l'appareil tombe toujours, il sera retiré et nous n'enregistrons pas la pression pendant que vous courez; vous ne serez pas retirée de l'étude.

Finalement, nous collerons un petit appareil nommé un accéléromètre avec du ruban adhésif sur la peau de votre bassin ainsi que de très minces semelles dans vos souliers. Nous vous ferons également porter une montre de type Fitbit sur votre poignet. Vous serez maintenant prête pour débiter le protocole de course. Mon assistante de recherche débutera le tapis de course et vous aidera à augmenter la vitesse afin de courir lentement à une vitesse de 7km/h pour 2 minutes. Par la suite, la vitesse sera augmentée à 10km/h pour 2 minutes et finalement à 15km/h pour 2 minutes. Par la suite, vous augmenterez ou réduirez la vitesse de course à votre vitesse confortable habituelle. Vous devrez choisir cette vitesse pour qu'elle soit considérée à modérément difficile tout en étant capable de la soutenir pour 30 minutes. Si vous êtes essoufflée ou vous êtes inconfortable, vous pourrez réduire la vitesse du tapis roulant ou marcher pour une minute avant de reprendre votre vitesse habituelle. Durant la course, nous vous demanderons de rapporter chaque épisode de fuite urinaire que vous ressentez, si vous en avez. Après 30 minutes de course à votre vitesse habituelle, nous ferons un petit retour au calme, suivi d'une course de 30 secondes à 10km/h et de 30 secondes à 7km/h. Durant la course, nous enregistrons deux petites vidéos en utilisant une caméra.

Immédiatement après la course, la serviette d'incontinence sera retirée et pesée. L'appareil intra-vaginal, les semelles dans vos souliers ainsi que le petit appareil collé sur votre hanche seront retirés. Vous aurez à décrire votre niveau de fatigue en utilisant une échelle. Les protocoles d'ultrason et de dynamomètre seront répétés.

Recommencer ici pour les femmes sédentaires.

Toutes les conversations pour cette étude seront tenues en français ou en anglais selon votre préférence. Par contre, quelques questionnaires n'ont pas été validés en français. Si vous avez de la difficulté à compléter ces questionnaires en anglais, je pourrai vous aider avec ces derniers durant votre visite au laboratoire.

Toutes mes excuses pour cette longue description des procédures de l'étude mais je veux m'assurer que vous compreniez totalement ce à quoi nous vous demandons de consentir. Avez-vous des questions? À ce point-ci, êtes-vous intéressée à vérifier si vous êtes éligible pour participer à cette étude?

Si non, prendre le temps de remercier la participante potentielle pour son temps et lui mentionner qu'elle peut nous contacter si elle change d'idée. Demandez-lui pourquoi elle refuse de poursuivre l'étude. Offrez-lui de lui envoyer la lettre d'information de l'étude ainsi que le formulaire de consentement afin qu'elle puisse les réviser et enregistrer la raison pour laquelle elle ne veut pas continuer l'étude.

Si oui, demandez-lui les questions suivantes en fonction de la cohorte :

À présent, je vais vous poser des questions pour vérifier si vous êtes éligible à participer à cette étude. Si vous ne comprenez pas les questions, laissez-le-moi savoir et je tenterai de vous fournir plus de détails.

Critères d'exclusion pour toutes les coureuses:

- Quel est votre âge? _____ (*non éligible si en bas de 18 ans)
- Êtes-vous enceinte? O [1] N [0]
- Avez-vous accouché dans la dernière année? O [1] N [0]
- Quel est votre grandeur? _____
- Quel est votre poids? _____
- Est-ce qu'un professionnel de la santé vous a déjà mentionné que vous étiez obèse?
O [1] N [0] (estimation de l'indice de masse corporel en fonction de l'information fournie.
Exclusion si l'estimation est plus élevée que 35kg/m² ou si la participante rapporte avoir
été informée qu'elle est obèse. L'indice de masse corporel sera confirmé à l'évaluation en
laboratoire.
- Est-ce que vous prenez de la médication pour les fuites urinaires? O [1] N [0]
- Avez-vous déjà reçu ou recevez-vous d'autres traitements pour les fuites urinaires? (tels
que les crèmes hormonales, les injections de collagène, la thérapie par laser ou tout autre
traitement) O [1] N [0]
- Avez-vous déjà eu une chirurgie gynécologique pour l'incontinence, descente
d'organe/prolapsus d'organe pelvienne ou pour l'endométriose ou autres chirurgies?
O [1] N [0]

Si oui, quelle chirurgie avez-vous subie.

Hystérectomie partielle	O 1	Ovariectomie	O 5
Hystérectomie complète	O 2	Colposuspension:	O 6
TVT	O 3	Autres _____	O 7
Ligation des tubes	O 4		

- Êtes-vous au courant si vous avez une condition neurologique telle que la sclérose en
plaque, une blessure à la moelle épinière, un accident vasculaire cérébral ou la maladie
de Parkinson? O [1] N [0]
- Avez-vous une condition qui pourrait affecter votre peau ou les tissus conjonctifs tels que
le syndrome de Marfan ou d'Ehlers-Danlos? O [1] N [0]
- Avez-vous des appareils métalliques dans votre bassin mis à part les stérilets? O [1] N [0]
- Êtes-vous au courant de problèmes de santé qui pourraient vous mettre à risque de faire
de l'activité physique? O [1] N [0]
- Avez-vous de la douleur lorsque vous insérez des tampons ou durant vos activités
sexuelles? O [1] N [0]
- Avez-vous de la douleur pelvienne? O [1] N [0]
- Êtes-vous au courant si vous avez une descente d'organe/prolapsus d'organes pelviens?
O [1] N [0]

Si oui, est-ce que ça sort de votre vagin lorsque vous forcez? O [1] N [0]

*** Les femmes ont besoin d'être capable de courir au moins 5 km en moins de 50 minutes (rythme minimum de 6km/h afin de s'assurer d'un impact élevé), au moins 2x/semaine (afin de s'assurer d'une fréquence adéquate), et depuis un minimum de 1 an (afin de s'assurer d'une durée d'exposition adéquate)***

- Combien de km courez-vous en moyenne par semaine? (doit être supérieur à 10km)

- Combien de fois par semaine courez-vous? _____ (doit être un minimum de 2x/semaine)
- Quelle est la durée moyenne de votre course?

- Êtes-vous capable de courir 5km en moins de 50 minutes?
_____ O [1] N [0] (non éligible si non)
- Depuis combien de temps courez-vous cette distance par semaine? (doit être supérieur à 1 an) _____
- Depuis combien de temps en mois ou années pratiquez-vous la course?

- Pouvez-vous maintenir une vitesse constante de course pendant 40 minutes sans arrêt O [1] N [0] (non éligible si non)

Critères d'exclusion pour les coureuses qui rapportent de l'incontinence urinaire

- Avez-vous des fuites d'urine lorsque vous courez? O [1] N [0]
À quelle fréquence ceci s'est produit durant le dernier mois (devrait être au minimum 1x/semaine)
 - Chaque course
 - Une fois par semaine
 - Plus d'une fois par semaine
 - Une fois par mois
 - 2-4 épisodes par mois
 - Plus de 5 épisodes par mois
- Est-ce que cette fuite d'urine est précédée par une envie urgente d'aller uriner? (non éligible si répond oui) O [1] N [0]
- Est-ce que vous avez des fuites urinaires durant d'autres activités? O [1] N [0]
Si oui, lesquelles? (s'assurer que ces activités sont associées à de l'effort)
 - Toux
 - Éternuement
 - Rire
 - Soulever une charge
 - Autre :

Combien de fois ces évènements se produisent-ils? (devrait être moins de 1x/mois)

- ☐ Chaque jour
- ☐ Chaque semaine
- ☐ Chaque mois
- ☐ Occasionnellement : quelques fois durant l'année
- ☐ Rarement : quelques fois au cours de votre vie
- ☐ Autre :

Critères d'exclusion pour les coureuses qui ne rapportent pas un historique d'incontinence urinaire

- Avez-vous déjà eu des fuites d'urine durant la course? O [1] N [0]

Critères d'exclusion pour les femmes sédentaires:

- Quel est votre âge? _____ (*non éligible si en bas de 18 ans)
- Faites-vous de l'activité physique autre que vos tâches quotidiennes? (non éligible si oui)
O [1] N [0]
Si oui, quelles sont ces activités physiques? _____
À quelle fréquence? _____
Avez-vous fait, dans le passé, de l'activité physique de façon régulière? O [1] N [0]
Si oui, quelles sont ces activités physiques? _____
À quelle fréquence? _____
- Êtes-vous enceinte? O [1] N [0]
- Avez-vous accouché dans la dernière année? O [1] N [0]
- Quel est votre grandeur? _____
- Quel est votre poids? _____
- Est-ce qu'un professionnel de la santé vous a déjà mentionné que vous étiez obèse? O [1] N [0] (estimation de l'indice de masse corporel en fonction de l'information fournie.
Exclusion si l'estimation est plus élevée que 35 kg/m² ou si la participante rapporte avoir été informée qu'elle est obèse. L'indice de masse corporel sera confirmé à l'évaluation en laboratoire.
- Avez-vous déjà eu une chirurgie gynécologique pour l'incontinence, descente d'organe/prolapsus d'organe pelvienne ou pour l'endométriose ou autres chirurgies?
O [1] N [0]
Si oui, quelle chirurgie avez-vous subie.

Hystérectomie partielle	O 1	Ovariectomie	O 5
Hystérectomie complète	O 2	Colposuspension:	O 6
TVT	O 3	Autres _____	O 7
Ligation des tubes	O 4		

- Est-ce que vous prenez de la médication pour les fuites urinaires? O [1] N [0]

- Avez-vous déjà reçu ou recevez-vous d'autres traitements pour les fuites urinaires? (tels que les crèmes hormonales, les injections de collagène, la thérapie par laser ou tout autre traitement) O [1] N [0]
- Êtes-vous au courant si vous avez une condition neurologique telle que la sclérose en plaque, une blessure à la moelle épinière, un accident vasculaire cérébral ou la maladie de Parkinson? O [1] N [0]
- Avez-vous une condition qui pourrait affecter votre peau ou les tissus conjonctifs tels que le syndrome de Marfan ou d'Ehlers-Danlos? O [1] N [0]
- Avez-vous des appareils métalliques dans votre bassin mis à part les stérilets? O [1] N [0]
- Avez-vous de la douleur lorsque vous insérez des tampons ou durant vos activités sexuelles? O [1] N [0]
- Avez-vous de la douleur pelvienne? O [1] N [0]
- Êtes-vous au courant si vous avez une descente d'organe/prolapsus d'organes pelviens? O [1] N [0]
Si oui, est-ce que ça sort de votre vagin lorsque vous forcez? O [1] N [0]

Critères d'exclusion pour les femmes sédentaires qui rapportent de l'incontinence urinaire:

- Est-ce que vous avez des fuites urinaires? O [1] N [0]

Combien de fois ces événements se produisent-ils? (devrait être moins de 1x/semaine)

- Chaque jour
- Presque qu'à chaque jour
- 1 x / semaine
- Plus de 2x/semaine
- 1 x / mois ou moins

Si oui, lesquelles? (s'assurer que ces activités sont associées à de l'effort)

- Toux
- Éternuement
- Rire
- Soulever une charge
- Autre : _____

- Est-ce que cette fuite d'urine est précédée par une envie urgente d'aller uriner? (non éligible si répond oui) O [1] N [0]

Critères d'exclusion pour les femmes sédentaires qui ne rapportent pas d'historique d'incontinence urinaire:

- Avez-vous déjà eu des fuites d'urine? O [1] N [0] (La réponse devrait être non ou pas depuis la dernière année)

Si oui, à quand remonte la dernière fuite urinaire? _____ ÉLIGIBLE? O [1] N [0]

Si non :

Merci de votre intérêt et de votre temps. Malheureusement, vous n'êtes pas éligible pour cette étude (expliquez le raisonnement). Désirez-vous que nous gardions votre nom et vos informations afin de vous contacter pour de futurs projets de recherche pour lesquels vous pourriez être éligible?

Consentement? O [1] N [0]

Avez-vous des questions? Encore une fois, je vous remercie de votre temps et passez une excellente journée. **Si oui :**

Merci de votre intérêt et de votre temps. Selon les informations que vous m'avez fournies, vous êtes éligible pour l'étude. Est-ce qu'il y a une raison, quelle qu'elle soit, selon vous, qui pourrait vous faire souffrir un stress émotionnel ou psychologique si vous faites les procédures de ce projet d'étude? O [1] N [0]. Si vous êtes encore intéressée, je vous enverrai par courriel, fax ou par la poste, la lettre d'information et le formulaire de consentement ainsi que les 7 questionnaires. Pourriez-vous me confirmer que ces informations pour vous contacter sont à jour? (vérifier si nous avons les bonnes informations). Avant de prendre un rendez-vous pour l'évaluation en laboratoire, j'ai besoin de savoir quand vos dernières menstruations ont commencé. Nous allons tenter de prendre rendez-vous juste après la fin de votre cycle menstruel (déterminer quelle semaine). Quel serait le meilleur moment pour prendre rendez-vous durant cette semaine? (prendre rendez-vous). Vous recevrez un courriel ou un appel avant l'évaluation afin de vous rappeler le rendez-vous et de vous donner les détails d'où vous présenter et de quoi amener. Préférez-vous un appel ou courriel, ou les 2?

Si coureuse et éligible, posez-cette question.

Afin de déterminer votre jambe dominante pour le protocole, j'ai besoin de savoir quel pied vous utilisez pour *kicker* une balle? D [1] G [0]

Avez-vous des questions?

Ceci complète l'entrevue téléphonique. Merci beaucoup pour votre temps et passez une excellente journée. N'hésitez pas à nous contacter si vous avez besoin d'informations supplémentaires.

Telephone Screening Form**Name:** _____**Date of screening:** _____(yyyy-mm-dd)

Home #: () - (best time to call:) leave a message? Y N

Cell #: () - (best time to call:) leave a message? Y N

Work #: () - (best time to call:) leave a message? Y N

Mailing address OR fax # (only if necessary) to send the questionnaires and LOI before the in-lab assessment:

Email address: _____

Call or email Log:

<u>Date</u>	<u>Time</u>	<u>RA</u>	<u>Outcome</u>
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Notes:

Appendix J: Data collection form

Date: _____

Participant ID: _____

Participant Screening and Data Collection Form for Runners

Date of birth? _____

Gravidity? (number of times pregnant) _____

Parity? (number of pregnancies to term) _____

When? _____

vaginal deliveries? _____

Use of forceps? _____

Use of suction? _____

Hysterectomy? _____

Menopausal status? _____

Smoker? _____

If yes, # packs per day? _____

Other relevant information? _____

How would you describe your ethnic origin?

* American Indian or Alaskan native (1)

* Asian/Pacific/Oriental (2)

* Black (3) → * Black African (3.1) * African American (3.2) * Black Caribbean (3.3)

* Native Hawaiian or other Pacific Islanders (4)

* White (5) → * North/West European (5.1) * East European (5.2) * South European (5.3)

* North American (5.4)

* Mixed Race (6)

* Other: _____ (please specify)

Do you consider yourself to be Spanish/Hispanic/Latina? * No * Yes

Have you ever done pelvic floor muscle exercises? * No * Yes

If yes, when?: _____

For how long (months/years)?: _____

How many contractions per day on average? _____

Are you currently doing them? (in the last month): * No * Yes

When was your last period (first day of bleeding)? _____

Date: _____

Participant ID: _____

LOI and consent form done O Yes O No
COVID-19 screening done O Yes O No
COVID-19 consent addendum done O Yes O No

Questionnaires:

ICIQ-FLUTS ☐
ICIQ-VS ☐
ICIQ-BS ☐
Par-Q ☐
LEAF ☐
IPAQ ☐
L-PAQ ☐

Participant height _____
Participant weight _____
Waist circumference _____
Hip circumference _____

- ☐ Researcher is wearing full PPE (lab coat, goggles or face shield, 3-layer mask)
- ☐ Research assistant is wearing full PPE (lab coat, goggles or face shield, 3-layer mask)
- ☐ 3-layer mask offered and worn by participant

Date: _____

Participant ID: _____

Visual inspection of the perineum and vulva – Select all that apply

- 1 ☐ Color: Erythema/redness
- 2 ☐ No abnormalities apparent
- 3 ☐ Scarring
- 4 ☐ Fissure
- 5 ☐ Lichen signs
- 6 ☐ Prolapse that goes beyond hymen

Visual observation of the pelvic floor muscle responses– Select all that apply

1. PFM response when asked to perform a voluntary contraction:

- 1 ☐ No visible contraction
- 2 ☐ Mild contraction
- 3 ☐ Good Contraction

Antero-posterior mobility Yes ☐1 No ☐2

Cranial mobility Yes ☐1 No ☐2

Compensations ☐ Which ones? _____

Inversion of command Yes ☐1 No ☐2

2. PFM response when asked to cough:

Contraction reflex present? Yes ☐1 No ☐2

Caudal descent Yes ☐1 No ☐2 degree? mild ☐1 mod ☐2 severe ☐3

3. PFM response when asked to perform a valsalva maneuver (i.e. bear down):

Contraction Yes ☐1 No ☐2

Caudal descent Yes ☐1 No ☐2 degree? mild ☐1 mod ☐2 severe ☐3

Contraction of Abdominal muscles Yes ☐1 No ☐2

Dermatomes: Light Touch

	Right	Left	Symmetrical	Side with less sensation (if applicable)
S1	☐ present	☐ present	☐ yes ☐ no	☐ Right ☐ Left
S2	☐ present	☐ present	☐ yes ☐ no	☐ Right ☐ Left
S3	☐ present	☐ present	☐ yes ☐ no	☐ Right ☐ Left
S4	☐ present	☐ present	☐ yes ☐ no	☐ Right ☐ Left

Date: _____

Participant ID: _____

Reflexes:

Anal wink	☐ present	☐ absent
-----------	-------------------------------	------------------------------

Intra-vaginal palpation: 2 Fingers

Tone of PFMs 6 o'clock: (i.e. resistance to passive stretch using 2 fingers)

-3	-2	-1	0	+1	+2	+3
Very Hypotonic	Hypotonic	Slightly Hypotonic	Normal Tone	Slightly Hypertonic	Hypertonic	Very Hypertonic

Pain? Yes O1 No O2

If yes (pain intensity from 0 to 10): _____

Contractility (i.e. Manual Muscle Testing using the Oxford Scale using 2 fingers)

Instructions on how to perform good PFM contraction + practice

PERFECT Scheme:

Power 6 o'clock:: *Contract as strong as you can*

0	1	2	3	4	5
No discernible muscle contraction	A flicker or pulsation is felt under the examiner's finger	An increase in tension is detected, without any discernible lift	Muscle tension is further enhanced and characterised by lifting of the muscle belly and also elevation of the posterior vaginal wall.	Increased tension and a good contraction are present which are capable of elevating the posterior vaginal wall against resistance	Strong resistance can be applied to the elevation of the posterior vaginal wall; the examining finger is squeezed and drawn into the vagina

Endurance: *Contract as strong as you can for as long as you can*

How long can the contraction be held before drop of 35%

Held for _____ **seconds**

Repetitions: *Contract as strong as you can for as long as you can and we will repeat this as many times as you can, up to a maximum of 10 times*

4 seconds rest between contractions

Above contraction repeated _____ **times**

60 seconds rest before next task

Fast: *Contract as fast and as strong as you can every second, up to a maximum of 10 times*

1sec MVCs _____ **times**

Date: _____

Participant ID: _____

US:

☐ Bladder volume between 100 – 200 mL

Pre Bladder volume = _____

If bladder volume is under 100mL, the woman will be asked to drink 100mL of water and to wait 10 minutes; if it is over 200mL she will be asked to void a small amount to bring the volume within a range of 100-200mL.

Bladder volume after waiting 10 minutes = _____

Void: yes ☐ no ☐

Supine: Examination plinth with legs supported and trunk inclined to 30 degrees

For these trials, you just have to stay very still while we collect images from your urethra.

Urethra Trial 1 ☐ Trial 2 ☐ Trial 3 ☐

Standing: Back against wall, hips flexed 15 degrees and feet 40 cm apart at heels

For these trials the rest data will be taken from the start of the task before the command is given.

3D - Rest command: Breathe in, breathe out, relax... Press "start data collection" when participant exhales

Rest Trial 1 ☐

3D - MVM command: Breathe in, breathe out, and bear down, bear down, bear down... Start US data collection when participant is given command to exhale

MVM Trial 1 ☐ Trial 2 ☐ Trial 3 ☐

2D - MVM command: Breathe in, breathe out, and bear down, bear down, bear down... Start US data collection when participant is given command to exhale

MVM Trial 1 ☐ Trial 2 ☐ Trial 3 ☐

2D - MVC command: Breathe in, breathe out, and squeeze, squeeze, squeeze... Start data collection on US on breathe out command

MVC Trial 1 ☐ Trial 2 ☐ Trial 3 ☐

Date: _____

Participant ID: _____

Dynamometer:

Dynamometer arms securely in position, covered ☐

Lubricant applied ☐

Dynamometer settings: Active program

Standing: Back against wall, hips flexed 15 degrees and feet 40 cm apart at heels

Opening speed: 15mm/s Max opening: 35mm Hold time: 30s

MVC command: *Breathe in, breathe out, and squeeze, squeeze, squeeze...*

MVC Trial 1 ☐ Trial 2 ☐ Trial 3 ☐

Supine: Examination plinth with legs supported and trunk inclined to 30 degrees

- ☐ **Set up EMG electrodes on the perineum to record EMG activity during passive stretch**
- Recording electrode over the left perianal region
 - Reference electrode to the skin surface at the anterior superior iliac spine on the left side

Dynamometer settings: Passive

Opening speed: 50mm/s Max opening: 40mm Hold time: 7s

Passive stretch: *Take deep breaths and try to keep your muscles relaxed as the arms open*

Resistance to passive stretch Trial 1 ☐ Trial 2 ☐ Trial 3 ☐

RECORD TYPE OF SHOE

Model of shoe: _____

Size of shoe: _____

☐ Picture

IAP sensor #: _____

Date: _____

Participant ID: _____

RUNNING PROTOCOL

- ☐ Set up participant with accelerometers on the mid-portion of the left iliac crest
- ☐ Zero sensor
- ☐ Start timer
- ☐ Wait until the sensor zeros and stop timer
- ☐ Participant inserts intra-vaginal sensor
- ☐ Intra-vaginal digital palpation by physiotherapist to make sure that the sensor is positioned adequately
- ☐ Weight of incontinence pad before= _____ grams
- ☐ Put lycra shorts with incontinence pad adhered to it
- ☐ Plug in IAP sensor and put IM on the left iliac crest and start back timer
- ☐ Stand upright for 1 min
- ☐ Right side for 1 min
- ☐ Supine for 8 minutes
 - ☐ Participant is not moving for 8 minutes
- ☐ Intra-vaginal digital palpation by physiotherapist to make sure that the sensor is positioned adequately.
- ☐ Unplug IAP sensor
- ☐ 3 walks on the force plate with acceleration
- ☐ 3 jogs
- ☐ 3 runs
- ☐ Start IM
- ☐ Take 3 deep breaths
- ☐ 3 sharp coughs
- ☐ 3 Valsalva
- ☐ 3 lifting weights with 6.8 kg in each hand
- ☐ 3 vertical jumps
- ☐ Go on the treadmill and put security clip
- ☐ Fitbit on wrist and reset
- ☐ Explain the BORG scale
- ☐ On treadmill and 3 deep breaths

Don't forget to do jump prior to each task on the force plate

Run 2 minutes @ 4.4m/h (7km/h) ☐

Stop and take 2 breaths ☐

Run @ 6.2m/h (10km/h) for 2 minutes ☐

Stop and take 2 breaths ☐

Run @ 9.3m/h (15km/h) for 2 minutes ☐

Stop and take 2 breaths ☐

For each running task, collect accelerometer data for 15 seconds

Date: _____

Participant ID: _____

Run @ self-selected pace _____ for 30 minutes

Stop and take 2 breaths ☐

Run @ 6.2m/h (10km/h) for 30 seconds ☐

Stop and take 2 breaths ☐

Run 2 minutes @ 4.4/h (7km/h) for 30 seconds ☐

Stop and stand still for 30 sec ☐

Borg scale RPE: _____

While they stand still

- ☐ Remove accelerometer
- ☐ Unplug IAP sensor
- ☐ Remove Fitbit

Go in the assessment room

- ☐ Ask them to remove the IAP sensor in their vagina and take off their shoes, pants and underwear without sitting
- ☐ Weight incontinence pad and record

Weight of incontinence pad after= _____g

Did the participant stopped and walked at any time during the running protocol? Yes ☐ No ☐

If yes, record time on timer and time through the running task on treadmill:

Number of steps on the Fitbit: = _____

Date: _____

Participant ID: _____

Trial	Force plate	Accelerometer	Trial	Accelerometer
walk_1			Pre7	
walk_2			Pre10	
walk_3			Pre15	
jog_1			Self3	
jog_2			Self15	
jog_3			Self27	
run_1			Post10	
run_2			Post7	
run_3				

US:

Standing: Back against wall, hips flexed 15 degrees and feet 40 cm apart at heels

For these trials the rest data will be taken from the start of the task before the command is given.

3D - Rest command: *Breathe in, breathe out, relax... Press "start data collection" when participant exhales*

Rest Trial 1 ☐

3D - MVM command: *Breathe in, breathe out, and bear down, bear down, bear down... Start US data collection when participant is given command to exhale*

MVM Trial 1 ☐ Trial 2 ☐ Trial 3 ☐

2D - MVM command: *Breathe in, breathe out, and bear down, bear down, bear down... Start US data collection when participant is given command to exhale*

MVM Trial 1 ☐ Trial 2 ☐ Trial 3 ☐

2D - MVC command: *Breathe in, breathe out, and squeeze, squeeze, squeeze... Start data collection on US on breathe out command*

MVC Trial 1 ☐ Trial 2 ☐ Trial 3 ☐

Date: _____

Participant ID: _____

Dynamometer settings: Active program

Standing: Back against wall, hips flexed 15 degrees and feet 40 cm apart at heels

Opening speed: 15mm/s Max opening: 35mm Hold time: 30s

MVC command: *Breathe in, breathe out, and squeeze, squeeze, squeeze...*

MVC Trial 1 ☐ Trial 2 ☐ Trial 3 ☐

Supine: Examination plinth with legs supported and trunk inclined to 30 degrees

- ☐ **Set up EMG electrodes on the perineum to record EMG activity during passive stretch**
- Recording electrode over the left perianal region
 - Reference electrode to the skin surface at the anterior superior iliac spine on the left side

Dynamometer settings: Passive

Opening speed: 50mm/s Max opening: 40mm Hold time: 7s

Passive stretch: *Take deep breaths and try to keep your muscles relaxed as the arms open*

Resistance to passive stretch Trial 1 ☐ Trial 2 ☐ Trial 3 ☐

Post Bladder volume = _____

Date: _____

Participant ID: _____

- | | |
|--|--------------------------|
| Laundry away | ☐ |
| Plinth disinfected | ☐ |
| US probes disinfected with high level disinfection | ☐ |
| US surface disinfected | ☐ |
| IAP sensor soap | ☐ |
| IAP sensor Tspray | ☐ |
| Discard dynamometer arms | ☐ |
| T-spray dynamometer | ☐ |
| Clean EMG wires with disinfectant wipes | ☐ |
| Discard EMG electrode | ☐ |
| Wipe treadmill console | ☐ |
| Wipe treadmill plexiglass | ☐ |
| Put sign on door in E104 to not use this room for 24 hours | ☐ |
| Wipe Fitbit | ☐ |
| Wipe table surface where the participant completed the consent | ☐ |

Assessment Completed by: _____

Signature: _____ **Date:** _____

Appendix K: ICIQ-FLUTS (English & French)

Initial number

ICIQ-FLUTS 08/04

CONFIDENTIAL

DAY MONTH YEAR

Today's date

Urinary symptoms

Many people experience urinary symptoms some of the time. We are trying to find out how many people experience urinary symptoms, and how much they bother them. We would be grateful if you could answer the following questions, thinking about how you have been, on average, over the PAST FOUR WEEKS.

1. Please write in your date of birth:

DAY MONTH YEAR

2a. During the night, how many times do you have to get up to urinate, on average?

- none ☐ 0
one ☐ 1
two ☐ 2
three ☐ 3
four or more ☐ 4

2b. How much does this bother you?

Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

3a. Do you have a sudden need to rush to the toilet to urinate?

- never ☐ 0
occasionally ☐ 1
sometimes ☐ 2
most of the time ☐ 3
all of the time ☐ 4

3b. How much does this bother you?

Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

4a. Do you have pain in your bladder?

- never ☐ 0
occasionally ☐ 1
sometimes ☐ 2
most of the time ☐ 3
all of the time ☐ 4

4b. How much does this bother you?

Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

5a. How often do you pass urine during the day?

1 to 6 times	☐	0
7 to 8 times	☐	1
9 to 10 times	☐	2
11 to 12 times	☐	3
13 or more times	☐	4

5b. How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0	1	2	3	4	5	6	7	8	9	10
not at all										a great deal

F score: sum scores 2a-5a ☐ ☐

6a. Is there a delay before you can start to urinate?

never	☐	0
occasionally	☐	1
sometimes	☐	2
most of the time	☐	3
all of the time	☐	4

6b. How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0	1	2	3	4	5	6	7	8	9	10
not at all										a great deal

7a. Do you have to strain to urinate?

never	☐	0
occasionally	☐	1
sometimes	☐	2
most of the time	☐	3
all of the time	☐	4

7b. How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0	1	2	3	4	5	6	7	8	9	10
not at all										a great deal

8a. Do you stop and start more than once while you urinate?

never ☐ 0

occasionally ☐ 1

sometimes ☐ 2

most of the time ☐ 3

all of the time ☐ 4

8b. How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
 not at all a great deal

V score: sum scores 6a+7a+8a ☐ ☐

9a. Does urine leak before you can get to the toilet?

never ☐ 0

occasionally ☐ 1

sometimes ☐ 2

most of the time ☐ 3

all of the time ☐ 4

9b. How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
 not at all a great deal

10a. How often do you leak urine?

never ☐ 0

once or less per week ☐ 1

two to three times per week ☐ 2

once per day ☐ 3

several times per day ☐ 4

10b. How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
 not at all a great deal

11a. Does urine leak when you are physically active, exert yourself, cough or sneeze?

never ☐ 0

occasionally ☐ 1

sometimes ☐ 2

most of the time ☐ 3

all of the time ☐ 4

11b. How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
 not at all a great deal

12a. Do you ever leak urine for no obvious reason and without feeling that you want to go?

never ☐ 0

occasionally ☐ 1

sometimes ☐ 2

most of the time ☐ 3

all of the time ☐ 4

12b. How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
 not at all a great deal

13a. Do you leak urine when you are asleep?

never ☐ 0

occasionally ☐ 1

sometimes ☐ 2

most of the time ☐ 3

all of the time ☐ 4

13b. How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
 not at all a great deal

I score: sum scores9a-13a

Thank you very much for answering these questions.

Numéro du participant

ICIQ-FLUTS (French) 01/07

CONFIDENTIEL

J J M M A A

Vous répondez à ce questionnaire le:

QUESTIONNAIRE SUR LES SYMPTOMES URINAIRES

Nous allons essayer de déterminer dans quelle mesure vos troubles urinaires sont un problème pour vous. Nous vous serions reconnaissants de bien vouloir nous aider en remplissant ce questionnaire. Lorsque vous répondrez aux questions, pensez aux symptômes que vous avez eus au cours des 4 DERNIERES SEMAINES.

1. Votre date de naissance :

JOUR

MOIS

ANNEE

2a. Pendant la nuit, combien de fois devez-vous vous lever pour uriner, en moyenne?

0 fois 01 fois 12 fois 23 fois 34 fois ou plus 4

2b. Est-ce un problème pour vous?

Entourez un chiffre entre 0 (Ce n'est pas un problème) et 10 (C'est un gros problème)

0 1 2 3 4 5 6 7 8 9 10

Ce n'est pas un problème

C'est un gros problème

3a. Devez-vous vous précipiter aux toilettes pour uriner?

jamais 0rarement 1quelquefois 2la plupart du temps 3tout le temps 4

3b. Est-ce un problème pour vous?

Entourez un chiffre entre 0 (Ce n'est pas un problème) et 10 (C'est un gros problème)

0 1 2 3 4 5 6 7 8 9 10

Ce n'est pas un problème

C'est un gros problème

4a. Avez-vous des douleurs dans la vessie?

jamais 0rarement 1quelquefois 2la plupart du temps 3tout le temps 4

4b. Est-ce un problème pour vous?

Entourez un chiffre entre 0 (Ce n'est pas un problème) et 10 (C'est un gros problème)

0 1 2 3 4 5 6 7 8 9 10

Ce n'est pas un problème

C'est un gros problème

5a. Pendant la journée, combien de fois urinez-vous, en moyenne?

1 à 6 fois ☐ 0
7 ou 8 fois ☐ 1
9 ou 10 fois ☐ 2
11 ou 12 fois ☐ 3
13 fois ou plus ☐ 4

5b. Est-ce un problème pour vous?
Entourez un chiffre entre 0 (Ce n'est pas un problème) et 10 (C'est un gros problème)

0 1 2 3 4 5 6 7 8 9 10
Ce n'est pas un problème C'est un gros problème

F score: ajoutez les scores 2a-5a ☐ ☐

6a. Y a-t-il un moment d'attente avant que vous puissiez commencer à uriner?

jamais ☐ 0
rarement ☐ 1
quelquefois ☐ 2
la plupart du temps ☐ 3
tout le temps ☐ 4

6b. Est-ce un problème pour vous?
Entourez un chiffre entre 0 (Ce n'est pas un problème) et 10 (C'est un gros problème)

0 1 2 3 4 5 6 7 8 9 10
Ce n'est pas un problème C'est un gros problème

7a. Devez-vous faire un effort pour arriver à uriner?

jamais ☐ 0
rarement ☐ 1
quelquefois ☐ 2
la plupart du temps ☐ 3
tout le temps ☐ 4

7b. Est-ce un problème pour vous?
Entourez un chiffre entre 0 (Ce n'est pas un problème) et 10 (C'est un gros problème)

0 1 2 3 4 5 6 7 8 9 10
Ce n'est pas un problème C'est un gros problème

8a. Pendant que vous urinez, votre jet d'urine s'arrête-t-il plus d'une fois, sans que vous le vouliez?

jamais ☐ 0
rarement ☐ 1
quelquefois ☐ 2
la plupart du temps ☐ 3
tout le temps ☐ 4

8b. Est-ce un problème pour vous?
Entourez un chiffre entre 0 (Ce n'est pas un problème) et 10 (C'est un gros problème)

0 1 2 3 4 5 6 7 8 9 10
Ce n'est pas un problème C'est un gros problème

V score: ajoutez les scores 6a+7a+8a

9a. Avez-vous des fuites d'urine avant de pouvoir arriver aux toilettes?

jamais ☐ 0
rarement ☐ 1
quelquefois ☐ 2
la plupart du temps ☐ 3
tout le temps ☐ 4

9b. Est-ce un problème pour vous?
Entourez un chiffre entre 0 (Ce n'est pas un problème) et 10 (C'est un gros problème)

0 1 2 3 4 5 6 7 8 9 10
Ce n'est pas un problème C'est un gros problème

10a. Avez-vous souvent des fuites d'urine?

jamais ☐ 0
environ une fois par semaine ☐ 1
2 ou 3 fois par semaine ☐ 2
une fois par jour ☐ 3
plusieurs fois par jour ☐ 4

10b. Est-ce un problème pour vous?
Entourez un chiffre entre 0 (Ce n'est pas un problème) et 10 (C'est un gros problème)

0 1 2 3 4 5 6 7 8 9 10
Ce n'est pas un problème C'est un gros problème

11a. Avez-vous des fuites d'urine au cours de vos activités physiques, quand vous faites un effort, quand vous toussiez ou éternuez?

jamais ☐ 0
rarement ☐ 1
quelquefois ☐ 2
la plupart du temps ☐ 3
tout le temps ☐ 4

11b. Est-ce un problème pour vous?
Entourez un chiffre entre 0 (Ce n'est pas un problème) et 10 (C'est un gros problème)

0 1 2 3 4 5 6 7 8 9 10
Ce n'est pas un problème C'est un gros problème

12a. Vous arrive-t-il d'avoir des fuites d'urine sans raison apparente et sans avoir envie d'aller aux toilettes?

jamais ☐ 0
rarement ☐ 1
quelquefois ☐ 2
la plupart du temps ☐ 3
tout le temps ☐ 4

12b. Est-ce un problème pour vous?
Entourez un chiffre entre 0 (Ce n'est pas un problème) et 10 (C'est un gros problème)

0 1 2 3 4 5 6 7 8 9 10
Ce n'est pas un problème C'est un gros problème

13a. Avez-vous des fuites d'urine pendant votre sommeil?

jamais ☐ 0
rarement ☐ 1
quelquefois ☐ 2
la plupart du temps ☐ 3
tout le temps ☐ 4

13b. Est-ce un problème pour vous?
Entourez un chiffre entre 0 (Ce n'est pas un problème) et 10 (C'est un gros problème)

0 1 2 3 4 5 6 7 8 9 10
Ce n'est pas un problème C'est un gros problème

I score: ajoutez les scores 9a-13a

Appendix L: ICIQ-VS (English & French)

Initial number

ICIQ-VS 10/05

CONFIDENTIAL

VAGINAL SYMPTOMS QUESTIONNAIRE

Many people experience vaginal symptoms some of the time. We are trying to find out how many people experience vaginal symptoms, and how much they bother them. We would be grateful if you could answer the following questions, thinking about how you have been, on average, over the PAST FOUR WEEKS.

Please write in today's date:

DAY MONTH YEAR

Please write in your date of birth:

DAY MONTH YEAR

Vaginal symptoms

1a. Are you aware of dragging pain in your lower abdomen?

- never 0
occasionally 1
sometimes 2
most of the time 3
all of the time 4

1b. How much does this bother you?

Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

2a. Are you aware of soreness in your vagina?

- never 0
occasionally 1
sometimes 2
most of the time 3
all of the time 4

2b. How much does this bother you?

Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

3a. Do you feel that you have reduced sensation or feeling in or around your vagina?

not at all ☐ 0
a little ☐ 1
somewhat ☐ 2
a lot ☐ 3

3b. How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

Prolapse is a common condition affecting the normal support of the pelvic organs, which results in descent or 'dropping down' of the vaginal walls and/or the pelvic organs themselves. This can include the bladder, the bowel and the womb. Symptoms are usually worse on standing up and straining (e.g. lifting, coughing or exercising) and usually better when lying down and relaxing.

Prolapse may cause a variety of problems. We are trying to find out how many people experience prolapse, and how much this bothers them. We would be grateful if you could answer the following questions, thinking about how you have been, on average, over the PAST FOUR WEEKS.

4a. Do you feel that your vagina is too loose or lax?

not at all ☐ 0
a little ☐ 1
somewhat ☐ 2
a lot ☐ 3

4b. How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

5a. Are you aware of a lump or bulge coming down in your vagina?

never ☐ 0
occasionally ☐ 1
sometimes ☐ 2
most of the time ☐ 3
all of the time ☐ 4

5b. How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

6a. Do you feel a lump or bulge come out of your vagina, so that you can feel it on the outside or see it on the outside?

never ☐ 0
occasionally ☐ 1
sometimes ☐ 2
most of the time ☐ 3
all of the time ☐ 4

6b. How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 **10**
not at all a great deal

7a. Do you feel that your vagina is too dry?

never ☐ 0
occasionally ☐ 1
sometimes ☐ 2
most of the time ☐ 3
all of the time ☐ 4

7b. How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 **10**
not at all a great deal

8a. Do you have to insert a finger into your vagina to help empty your bowels?

never ☐ 0
occasionally ☐ 1
sometimes ☐ 2
most of the time ☐ 3
all of the time ☐ 4

8b. How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 **10**
not at all a great deal

9a. Do you feel that your vagina is too tight?

never ☐
occasionally ☐
sometimes ☐
most of the time ☐
all of the time ☐

9b. How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 **10**
not at all a great deal

Sexual matters

We would be grateful if you could answer the following questions, thinking about how you have been, on average, over the PAST FOUR WEEKS.

10. Do you have a sex life at present?

- yes ☐ 1
no, because of my vaginal symptoms ☐ 0
no, because of other reasons ☐ 2

If NO, please go to question 14

11a. Do worries about your vagina interfere with your sex life?

- not at all ☐ 0
a little ☐ 1
somewhat ☐ 2
a lot ☐ 3

11b. How much does this bother you?

Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

12a. Do you feel that your relationship with your partner is affected by vaginal symptoms?

- not at all ☐ 0
a little ☐ 1
somewhat ☐ 2
a lot ☐ 3

12b. How much does this bother you?

Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

13. How much do you feel that your sex life has been spoilt by vaginal symptoms?

Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

Quality of life

We would be grateful if you could answer the following questions, thinking about how you have been, on average, over the PAST FOUR WEEKS.

14. Overall, how much do vaginal symptoms interfere with your everyday life?												
<i>Please ring a number between 0 (not at all) and 10 (a great deal)</i>												
0	1	2	3	4	5	6	7	8	9	10		
not at all											a great deal	

Thank you very much for answering these questions.

VAGINAL SYMPTOMS QUESTIONNAIRE

SCORING

(This section is for administrative use only)

Patient number

--	--	--	--	--	--	--	--	--	--

Vaginal symptoms score

Vaginal symptom score = 2×(dragging pain) + 2×(soreness in vagina) + (reduced sensation) + 2×(vagina too loose) + 2×(lump felt inside) + 2×(lump seen outside) + 2×(vagina too dry) + (faecal evacuation)

symptom*	score	weighted score
Q1. 'dragging pain'		x 2 =
Q2. 'soreness in vagina'		x 2 =
Q3. 'reduced sensation'		x 1 =
Q4. 'vagina too loose'		x 2 =
Q5. 'lump felt inside'		x 2 =
Q6. 'lump seen outside'		x 2 =
Q7. 'vagina too dry'		x 2 =
Q8. 'faecal evacuation'		x 1 =
Total vaginal symptoms score		

*(Note: Q9, 'vagina too tight', is primarily for detecting a potential post-treatment complication and is therefore not included in the scoring)

Sexual matters score

Sexual matters score = (sex-life spoilt) + 8×(worries about vagina interfere with sex-life) + 8×(relationship affected)

sexual matter	score	weighted score
Q11. 'worries about vagina interfere with sex-life'		x 8 =
Q12. 'relationship affected'		x 8 =
Q13. 'sex life spoilt'		x 1 =
Total sexual matters score		

Quality of life score

quality of life	score
Q14. 'quality of life affected'	

QUESTIONNAIRE SUR LES SYMPTÔMES VAGINAUX

Plusieurs femmes éprouvent des symptômes vaginaux à l'occasion. Nous souhaitons déterminer combien de femmes éprouvent de tels symptômes et jusqu'à quel point ils les ennuiant. Nous vous serions reconnaissant de répondre aux questions ci-dessous en tenant compte de ce que vous avez expérimenté, de façon générale, au cours des QUATRE DERNIÈRES SEMAINES.

Veillez inscrire la date du jour :

JOUR MOIS ANNÉE

Veillez inscrire votre date de naissance :

JOUR MOIS ANNÉE

Symptômes vaginaux

1a. Ressentez-vous des douleurs persistantes au bas-ventre ?

Jamais _ 0
Rarement _ 1
Parfois _ 2
La plupart du temps _ 3
Tout le temps _ 4

1b. Jusqu'à quel point cela vous ennuie-t-il ?

Veillez encercler un chiffre entre 0 (pas du tout) et 10 (beaucoup).

0 1 2 3 4 5 6 7 8 9 10
Pas du tout Beaucoup

2a. Ressentez-vous une douleur constante dans le vagin ?

Jamais _ 0
Rarement _ 1
Parfois _ 2
La plupart du temps _ 3
Tout le temps _ 4

2b. Jusqu'à quel point cela vous ennuie-t-il ?

Veillez encercler un chiffre entre 0 (pas du tout) et 10 (beaucoup).

0 1 2 3 4 5 6 7 8 9 10
Pas du tout Beaucoup

3a. Avez-vous l'impression que la sensibilité dans le vagin ou dans la région vaginale a diminué ?

Pas du tout _ 0
À peine _ 1
Quelque peu _ 2
Beaucoup _ 3

3b. Jusqu'à quel point cela vous ennuie-t-il ?

Veillez encercler un chiffre entre 0 (pas du tout) et 10 (beaucoup).

0 1 2 3 4 5 6 7 8 9 10

Pas du tout

Beaucoup

La descente d'organes (prolapsus) est un phénomène courant qui influence le soutènement normal des organes pelviens et qui entraîne le glissement vers le bas et (ou) la chute des parois vaginales ou des organes pelviens eux-mêmes, notamment la vessie, l'intestin et l'utérus. Habituellement, les symptômes s'aggravent en position debout et à l'effort (p. ex., soulèvement d'un objet, toux ou exercice) et diminuent en position couchée et au repos.

Le prolapsus peut entraîner divers problèmes. Nous souhaitons déterminer combien de femmes souffrent d'un prolapsus et jusqu'à quel point cela les ennuie. Nous vous serions reconnaissant de répondre aux questions ci-dessous en tenant compte de ce que vous avez expérimenté, de façon générale, au cours des QUATRE DERNIÈRES SEMAINES.

4a. Sentez-vous que votre vagin est trop flasque ou relâché ?

Pas du tout _ 0
À peine _ 1
Quelque peu _ 2
Beaucoup _ 3

4b. Jusqu'à quel point cela vous ennuie-t-il ?

Veillez encercler un chiffre entre 0 (pas du tout) et 10 (beaucoup).

0 1 2 3 4 5 6 7 8 9 10

Pas du tout

Beaucoup

5a. Sentez-vous une bosse ou un renflement descendre dans le vagin ?

Jamais _ 0
Rarement _ 1
Parfois _ 2
La plupart du temps _ 3
Tout le temps _ 4

5b. Jusqu'à quel point cela vous ennuie-t-il ?

Veillez encercler un chiffre entre 0 (pas du tout) et 10 (beaucoup).

0 1 2 3 4 5 6 7 8 9 10

Pas du tout

Beaucoup

6a. Sentez-vous une bosse ou un renflement descendre dans le vagin au point où vous pouvez le palper ou le voir à l'extérieur ?

Jamais _ 0
Rarement _ 1
Parfois _ 2
La plupart du temps _ 3
Tout le temps _ 4

6b. Jusqu'à quel point cela vous ennue-t-il ?

Veillez encercler un chiffre entre 0 (pas du tout) et 10 (beaucoup).

0 1 2 3 4 5 6 7 8 9 10
Pas du tout Beaucoup

7a. Ressentez-vous de la sécheresse vaginale ?

Jamais _ 0
Rarement _ 1
Parfois _ 2
La plupart du temps _ 3
Tout le temps _ 4

7b. Jusqu'à quel point cela vous ennue-t-il ?

Veillez encercler un chiffre entre 0 (pas du tout) et 10 (beaucoup).

0 1 2 3 4 5 6 7 8 9 10
Pas du tout Beaucoup

8a. Devez-vous introduire un doigt dans le vagin pour aider à évacuer vos selles ?

Jamais _ 0
Rarement _ 1
Parfois _ 2
La plupart du temps _ 3
Tout le temps _ 4

8b. Jusqu'à quel point cela vous ennue-t-il ?

Veillez encercler un chiffre entre 0 (pas du tout) et 10 (beaucoup).

0 1 2 3 4 5 6 7 8 9 10
Pas du tout Beaucoup

9a. Sentez-vous que votre vagin est trop serré ?

Jamais _
Rarement _
Parfois _
La plupart du temps _
Tout le temps _

9b. Jusqu'à quel point cela vous ennue-t-il ?

Veillez encercler un chiffre entre 0 (pas du tout) et 10 (beaucoup).

0 1 2 3 4 5 6 7 8 9 10
Pas du tout Beaucoup

Sexualité

Nous vous serions reconnaissant de répondre aux questions ci-dessous en tenant compte de ce que vous avez expérimenté, de façon générale, au cours des QUATRE DERNIÈRES SEMAINES.

10. Avez-vous une vie sexuelle active en ce moment ?

Oui_1

Non, en raison de mes symptômes vaginaux 0

Non, pour d'autres raisons 2

Si vous avez répondu non, passez à la question 14.

11a. Est-ce que vos préoccupations relatives à votre vagin nuisent à votre vie sexuelle ?

Pas du tout_0

À peine 1

Quelque peu 2

Beaucoup _ 3

11b. Jusqu'à quel point cela vous ennuie-t-il ?

Veuillez encercler un chiffre entre 0 (pas du tout) et 10 (beaucoup).

0 1 2 3 4 5 6 7 8 9 10

Pas du tout

Beaucoup

12a. Sentez-vous que la relation avec votre partenaire est affectée par vos symptômes vaginaux ?

Pas du tout_0

À peine 1

Quelque peu 2

Beaucoup _ 3

12b. Jusqu'à quel point cela vous ennuie-t-il ?

Veuillez encercler un chiffre entre 0 (pas du tout) et 10 (beaucoup).

0 1 2 3 4 5 6 7 8 9 10

Pas du tout

Beaucoup

13. Jusqu'à quel point croyez-vous que votre vie sexuelle est perturbée par vos symptômes vaginaux?

Veuillez encercler un chiffre entre 0 (pas du tout) et 10 (beaucoup).

0 1 2 3 4 5 6 7 8 9 10

Pas du tout

Beaucoup

Qualité de vie

Nous vous serions reconnaissant de répondre aux questions ci-dessous en tenant compte de ce que vous avez expérimenté, de façon générale, au cours des QUATRE DERNIÈRES SEMAINES.

14. Dans l'ensemble, jusqu'à quel point vos symptômes vaginaux nuisent-ils à votre vie quotidienne?

Veuillez encercler un chiffre entre 0 (pas du tout) et 10 (beaucoup).

0 1 2 3 4 5 6 7 8 9 10

Pas du tout

Beaucoup

Nous vous remercions d'avoir répondu à ces questions.

QUESTIONNAIRE SUR LES SYMPTÔMES VAGINAUX

Cote

(Cette section est réservée à l'administration.)

Numéro de patiente

Cote – symptômes vaginaux

Note des symptômes vaginaux = $2 \times$ (douleurs persistantes) + $2 \times$ (douleur dans le vagin) + (diminution de la sensibilité) + $2 \times$ (vagin trop flasque) + $2 \times$ (bosse à l'intérieur) + $2 \times$ (bosse à l'extérieur) + $2 \times$ (sécheresse vaginale) + (évacuation des selles)

Symptômes *	Note	Note pondérée
Q1. Douleurs persistantes		$\times 2 =$
Q2. Douleur dans le vagin		$\times 2 =$
Q3. Diminution de la sensibilité		$\times 1 =$
Q4. Vagin trop flasque		$\times 2 =$
Q5. Bosse à l'intérieur		$\times 2 =$
Q6. Bosse à l'extérieur		$\times 2 =$
Q7. Sécheresse vaginale		$\times 2 =$
Q8. Évacuation des selles		$\times 1 =$
Note totale des symptômes vaginaux		

* (Remarque : la question 9 [vagin trop serré] sert surtout à détecter la possibilité d'une complication post-traitement et, en conséquence, elle est exclue de la cote.)

Cote – Sexualité

Note de la sexualité = (vie sexuelle perturbée) + $8 \times$ (préoccupations à propos du vagin nuisant à la vie sexuelle) + $8 \times$ (relation avec partenaire affectée)

Sexualité	Note	Note pondérée
Q11. Préoccupations à propos du vagin nuisant à la vie sexuelle		$\times 8 =$
Q12. Relation avec partenaire affectée		$\times 8 =$
Q13. Vie sexuelle perturbée		$\times 1 =$
Note totale de la sexualité		

Cote – qualité de vie

Qualité de vie	Note
Q14. Impact sur la qualité de vie	

Appendix M: ICIQ-B

Initial number

ICIQ-B (04/08)

CONFIDENTIAL

DAY MONTH YEAR

Today's date

Many people experience bowel accidents or bowel leakages. We are trying to find out how many people experience these symptoms and how much this bothers them. We would be grateful if you could answer the following questions, thinking about how you have been over the PAST THREE MONTHS.

1 Please write in your date of birth:

DAY MONTH YEAR

2 Are you (tick one):

Female ☐ Male ☐

Bowel pattern

3 On average how many times do you open your bowels in 24 hours?
(Tick one box for 'usual' and tick one box for 'at worst')

	(a) Usual	(b) At worst
less than once	☐ ¹	☐ ¹
one to three times	☐ ²	☐ ²
three to ten times	☐ ³	☐ ³
ten or more times	☐ ⁴	☐ ⁴

(c) **How much does this bother you?**
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

4 How often do you open your bowels during the night from going to bed to sleep until you get up in the morning? (Tick one box)

(a)

never ☐ ⁰

once ☐ ¹

twice ☐ ²

three times ☐ ³

four or more times ☐ ⁴

(b) **How much does this bother you?**
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

5 Do you have to rush to the toilet when you need to open your bowels?
(Tick one box)

(a)

never ☐ 0

rarely ☐ 1

some of the time ☐ 2

most of the time ☐ 3

always ☐ 4

(b) **How much does this bother you?**
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

6 Do you use medications (tablets or liquids) to stop you opening your bowels?
(Tick one box)

(a)

never ☐ 0

less than once a month ☐ 1

less than once a week ☐ 2

less than once a day ☐ 3

about once a day ☐ 4

several times a day ☐ 5

(b) **How much does this bother you?**
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

7 Do you experience pain/soreness around your back passage? (Tick one box)

(a)

never ☐ 0

rarely ☐ 1

some of the time ☐ 2

most of the time ☐ 3

always ☐ 4

(b) **How much does this bother you?**
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

Bowel pattern score: sum scores 3a - 7a

Bowel control

8 Do you experience any staining of your underwear or need to wear pads because of your bowels? (Tick one box)

(a)

never ☐ 0

less than once a month ☐ 1

less than once a week ☐ 2

less than once a day ☐ 3

everyday ☐ 4

(b) **How much does this bother you?**
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

9 Are you able to control watery or loose stool leaking from your back passage? (Tick one box)

(a)

always ☐ 0

most of the time ☐ 1

some of the time ☐ 2

rarely ☐ 3

never ☐ 4

(b) **How much does this bother you?**
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

10 Are you able to control accidental loss of formed or solid stool from your back passage? (Tick one box)

(a)

always ☐ 0

most of the time ☐ 1

some of the time ☐ 2

rarely ☐ 3

never ☐ 4

(b) **How much does this bother you?**
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

11 Are you able to control wind (flatus) escaping from your back passage?

(Tick one box)

(a)

always ☐ 0

most of the time ☐ 1

some of the time ☐ 2

rarely ☐ 3

never ☐ 4

(b) **How much does this bother you?**

Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

12 Are you able to control mucus (discharge) leaking from your back passage?

(Tick one box)

(a)

always ☐ 0

most of the time ☐ 1

some of the time ☐ 2

rarely ☐ 3

never ☐ 4

(b) How much does this bother you?

Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

13 Do you have bowel accidents when you have no need to open your bowels?

(Tick one box)

(a)

never ☐ 0

rarely ☐ 1

some of the time ☐ 2

most of the time ☐ 3

always 4

(b) How much does this bother you?

Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

14 Are your bowel accidents or leakages unpredictable? (Tick one box)

never ☐ (a) 0

rarely ☐ 1

some of the time ☐ 2

most of the time ☐ 3

always ☐ 4

(b) **How much does this bother you?**

Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

Bowel control score: sum scores 8a – 14a

Other bowel symptoms

15 Using the pictures please indicate how your bowel movements are most of the time? (Tick all boxes that apply)

separate hard lumps like nuts (hard to pass)  (a) 1

sausage-shaped but lumpy   2

like a sausage but with cracks on its surface 3

like a sausage or snake – smooth and soft  4

soft blobs with clear cut edges (easy to pass)  5

fluffy pieces with ragged edges, a mushy stool  6

watery, no solid pieces  7

(b) How much does this bother you?

Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

16 Do you need to strain to open your bowels? (Tick one box)

(a)

never ☐ 0

rarely ☐ 1

some of the time ☐ 2

most of the time ☐ 3

always ☐ 4

(b) How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 **10**
 not at all a great deal

17 Is the possibility of having a bowel accident on your mind? (Tick one box)

(a)

never ☐ 0

rarely ☐ 1

some of the time ☐ 2

most of the time ☐ 3

always ☐ 4

(b) How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 **10**
 not at all a great deal

Sexual impact

18 Do you restrict your sexual activities because of your bowels? (Tick one box)

(a)

never ☐ 0

rarely ☐ 1

some of the time ☐ 2

most of the time ☐ 3

always ☐ 4

not applicable ☐ 5

(b) How much does this bother you?
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 **10**
 not at all a great deal

Quality of life

19 Do your bowels cause you to feel embarrassed? (Tick one box)

(a)

never ☐ 0

rarely ☐ 1

some of the time ☐ 2

most of the time ☐ 3

always ☐ 4

(b) **How much does this bother you?**
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

20 Do your bowels cause you to make sure you know where toilets are? (Tick one box)

(a)

never ☐ 0

rarely ☐ 1

some of the time ☐ 2

most of the time ☐ 3

always ☐ 4

(b) **How much does this bother you?**
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

21 Do your bowels cause you to make plans according to your bowels? (Tick one box)

(a)

never ☐ 0

rarely ☐ 1

some of the time ☐ 2

most of the time ☐ 3

always ☐ 4

(b) **How much does this bother you?**
Please ring a number between 0 (not at all) and 10 (a great deal)

0 1 2 3 4 5 6 7 8 9 10
not at all a great deal

Appendix N: LEAF questionnaire

October 30, 2013 [THE LEAF-Q]



(Supplemental Digital Content 1)

The LEAF-Q

A questionnaire for female athletes

Department of Nutrition, Exercise and Sports
Life Science
University of Copenhagen
Denmark
Contact: Anna Melin, aot@life.ku.dk

The low energy availability in females questionnaire (LEAF-Q), focuses on physiological symptoms of insufficient energy intake. The following pages contain questions regarding injuries, gastrointestinal and reproductive function. We appreciate you taking the time to fill out the LEAF-Q and the reply will be treated as confidential.

Name: _____

Address: _____

E-mail: _____

Cell: _____

Profession: _____

Education: _____

Age: _____ (years)

Height: _____ (cm) Weight: _____ (kg)

Your highest weight with your present height: _____ (kg)
(excluding pregnancy)

Your lowest weight with your present height: _____ (kg)

Do you smoke? Yes ☐ No ☐

Do you use any medication (excluding oral contraceptives)? Yes ☐ No ☐

If yes, what kind of medication? _____

Your normal amount of training (average) – number of hours per week and what kind of exercise, such as running, swimming, bicycling, strength training, technique training etc.:

Comments or further information regarding exercise: _____

1. Injuries**Mark the response that most accurately describes your situation**

A: Have you had absences from your training, or participation in competitions during the last year due to injuries?

☐ No, not at all ☐ Yes, once or twice ☐ Yes, three or four times ☐ Yes, five times or more

A1: If yes, for how many days absence from training or participation in competition due to injuries have you had in the last year?

☐ 1-7 days ☐ 8-14 days ☐ 15-21 days ☐ 22 days or more

A2: If yes, what kind of injuries have you had in the last year? _____

Comments or further information regarding injuries: _____

2. Gastro intestinal function

A: Do you feel gaseous or bloated in the abdomen, also when you do not have your period?

☐ Yes, several times a day ☐ Yes, several times a week

☐ Yes, once or twice a week or more seldom ☐ Rarely or never

B: Do you get cramps or stomach ache which cannot be related to your menstruation?

☐ Yes, several times a day ☐ Yes, several times a week

☐ Yes, once or twice a week or more seldom ☐ Rarely or never

C: How often do you have bowel movements on average?

☐ Several times a day ☐ Once a day ☐ Every second day

☐ Twice a week ☐ Once a week or more rarely

D: How would you describe your normal stool?

☐ Normal (soft) ☐ Diarrhoea-like (watery) ☐ Hard and dry

Comments regarding gastrointestinal function: _____

3. Menstrual function and use of contraceptives

3.1 Contraceptives

Mark the response that most accurately describes your situation

A: Do you use oral contraceptives?

☐ Yes ☐ No

A1: If yes, why do you use oral contraceptives?

☐ Contraception ☐ Reduction of menstruation pains ☐ Reduction of bleeding

☐ To regulate the menstrual cycle in relation to performances etc..

☐ Otherwise menstruation stops

☐ Other _____

A2: If no, have you used oral contraceptives earlier?

☐ Yes ☐ No

A2.1: If yes, when and for how long? _____

B: Do you use any other kind of hormonal contraceptives? (e.g. hormonal implant or coil)

☐ Yes ☐ No

B1: If yes, what kind?

☐ Hormonal patches ☐ Hormonal ring ☐ Hormonal coil ☐ Hormonal implant ☐ Other

3.2 Menstrual function

Mark the response that most accurately describes your situation

A: How old were when you had your first period?

☐ 11 years or younger ☐ 12-14 years ☐ 15 years or older ☐ I don't remember☐ I have never menstruated (If you have answered "I have never menstruated" there are no further questions to answer)

B: Did your first menstruation come naturally (by itself)?

☐ Yes ☐ No ☐ I don't remember

B1: If no, what kind of treatment was used to start your menstrual cycle?

☐ Hormonal treatment ☐ Weight gain☐ Reduced amount of exercise ☐ Other

C: Do you have normal menstruation?

☐ Yes ☐ No (go to question C6) ☐ I don't know (go to question C6)

C1: If yes, when was your last period?

☐ 0-4 weeks ago ☐ 1-2 months ago ☐ 3-4 months ago ☐ 5 months ago or moreC2: If yes, are your periods regular? (Every 28th to 34th day)☐ Yes, most of the time ☐ No, mostly not

C3: If yes, for how many days do you normally bleed?

☐ 1-2 days ☐ 3-4 days ☐ 5-6 days ☐ 7-8 days ☐ 9 days or more

C4: If yes, have you ever had problems with heavy menstrual bleeding?

☐ Yes ☐ No

C5: If yes, how many periods have you had during the last year?

☐ 12 or more ☐ 9-11 ☐ 6-8 ☐ 3-5 ☐ 0-2

3.2 Menstrual function

Mark the response that most accurately describes your situation

C6: If no or "I don't remember", when did you have your last period?

- ☐ 2-3 months ago ☐ 4-5 months ago ☐ 6 months ago or more
☐ I'm pregnant and therefore do not menstruate

D: Have your periods ever stopped for 3 consecutive months or longer (besides pregnancy)?

- ☐ No, never ☐ Yes, it has happened before ☐ Yes, that's the situation now

E: Do you experience that your menstruation changes when you increase your exercise intensity, frequency or duration?

- ☐ Yes ☐ No

E1: If yes, how? (Check one or more options)

- ☐ I bleed less ☐ I bleed fewer days ☐ My menstruations stops
☐ I bleed more ☐ I bleed more days



(Supplemental Digital Content 2)

The LEAF-Q Scoring key

A total score ≥8 is to be considered at risk for the Triad

Department of Nutrition, Exercise and Sports
Life Science
University of Copenhagen
Denmark

Contact: Anna Melin, aot@life.ku.dk

1. A: 0 No, not at all, 1 Yes, once or twice, 2 Yes, three or four times, 3 Yes, five times or more
1. A1: 1 1-7 days, 2 8-14 days, 3 15-21 days, 4 22 days or more
2. A: 3 Yes, several times a day, 2 Yes, several times a week, 1 Yes, once or twice a week or more seldom,
0 Rarely or never
2. B: 3 Yes, several times a day, 2 Yes, several times a week, 1 Yes, once or twice a week or more seldom,
0 Rarely or never
2. C: 1 Several times a day, 0 Once a day, 2 Every second day, 3 Twice a week, 4 Once a week or more rarely
2. D: 0 Normal, 1 Diarrhoea-like, 2 Hard and dry
- 3.1 A1: 0 Contraception, 0 Reduction of menstruation pains, 0 Reduction of bleeding,
0 To regulate the menstrual cycle in relation to performances etc., 1 Otherwise menstruation stops
- 3.2 A: 0 11 years or younger, 0 12-14 years, 1 15 years or older, 0 I don't remember,
8 I have never menstruated
- 3.2 B: 0 Yes, 1 No, 1 I don't remember
- 3.2 B1: 1 Hormonal treatment, 1 Weight gain, 1 Reduced amount of exercise, 1 Other
- 3.2 C: 0 Yes, 2 No (go to question 3.2 C6), 1 I don't know (go to question 3.2 C6)
- 3.2 C1: 0 0-4 weeks ago, 1 1-2 months ago, 2 3-4 months ago, 3 5 months ago or more
- 3.2 C2: 0 Yes, most of the time, 1 No, mostly not
- 3.2 C3: 1 1-2 days, 0 3-4 days, 0 5-6 days, 0 7-8 days, 0 9 days or more
- 3.2 C4: 0 Yes, 0 No
- 3.2 C5: 0 12 or more, 1 9-11, 2 6-8, 3 3-5, 4 0-2
- 3.2 C6: 1 2-3 months ago, 2 4-5 months ago, 3 6 months ago or more
0 I'm pregnant and therefore do not menstruate
- 3.2 D: 0 No, never, 1 Yes, it has happened before, 2 Yes, that's the situation now
- 3.2 E: 1 Yes, 0 No
- 3.2 E1: 1 I bleed less, 1 I bleed fewer days, 2 My menstruations stops, 0 I bleed more, 0 I bleed more days

Appendix O: IPAQ

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (October 2002)

LONG LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health-related physical activity.

Background on IPAQ

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ

Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation

Translation from English is encouraged to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ

International collaboration on IPAQ is on-going and an *International Physical Activity Prevalence Study* is in progress. For further information see the IPAQ website.

More Information

More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective*. Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** and **moderate** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal.

PART 1: JOB-RELATED PHYSICAL ACTIVITY

The first section is about your work. This includes paid jobs, farming, volunteer work, course work, and any other unpaid work that you did outside your home. Do not include unpaid work you might do around your home, like housework, yard work, general maintenance, and caring for your family. These are asked in Part 3.

1. Do you currently have a job or do any unpaid work outside your home?

☐ Yes

☐ No →

Skip to PART 2: TRANSPORTATION

The next questions are about all the physical activity you did in the **last 7 days** as part of your paid or unpaid work. This does not include traveling to and from work.

2. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, heavy construction, or climbing up stairs **as part of your work**? Think about only those physical activities that you did for at least 10 minutes at a time.

_____ **days per week**

☐ No vigorous job-related physical activity



Skip to question 4

3. How much time did you usually spend on one of those days doing **vigorous** physical activities as part of your work?

_____ **hours per day**

_____ **minutes per day**

4. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads **as part of your work**? Please do not include walking.

_____ **days per week**

☐ No moderate job-related physical activity



Skip to question 6

5. How much time did you usually spend on one of those days doing **moderate** physical activities as part of your work?

_____ **hours per day**
_____ **minutes per day**

6. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **as part of your work**? Please do not count any walking you did to travel to or from work.

_____ **days per week**

☐

No job-related walking



Skip to PART 2: TRANSPORTATION

7. How much time did you usually spend on one of those days **walking** as part of your work?

_____ **hours per day**
_____ **minutes per day**

PART 2: TRANSPORTATION PHYSICAL ACTIVITY

These questions are about how you traveled from place to place, including to places like work, stores, movies, and so on.

8. During the **last 7 days**, on how many days did you **travel in a motor vehicle** like a train, bus, car, or tram?

_____ **days per week**

☐

No traveling in a motor vehicle



Skip to question 10

9. How much time did you usually spend on one of those days **traveling** in a train, bus, car, tram, or other kind of motor vehicle?

_____ **hours per day**
_____ **minutes per day**

Now think only about the **bicycling** and **walking** you might have done to travel to and from work, to do errands, or to go from place to place.

10. During the **last 7 days**, on how many days did you **bicycle** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐

No bicycling from place to place



Skip to question 12

11. How much time did you usually spend on one of those days to **bicycle** from place to place?
- _____ **hours per day**
 _____ **minutes per day**
12. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time to go **from place to place**?
- _____ **days per week**
- ☐ No walking from place to place → **Skip to PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY**
13. How much time did you usually spend on one of those days **walking** from place to place?
- _____ **hours per day**
 _____ **minutes per day**

PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY

This section is about some of the physical activities you might have done in the **last 7 days** in and around your home, like housework, gardening, yard work, general maintenance work, and caring for your family.

14. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, chopping wood, shoveling snow, or digging **in the garden or yard**?
- _____ **days per week**
- ☐ No vigorous activity in garden or yard → **Skip to question 16**
15. How much time did you usually spend on one of those days doing **vigorous** physical activities in the garden or yard?
- _____ **hours per day**
 _____ **minutes per day**
16. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, sweeping, washing windows, and raking **in the garden or yard**?
- _____ **days per week**
- ☐ No moderate activity in garden or yard → **Skip to question 18**

17. How much time did you usually spend on one of those days doing **moderate** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

18. Once again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, washing windows, scrubbing floors and sweeping **inside your home**?

_____ **days per week**

☐

No moderate activity inside home



***Skip to PART 4: RECREATION,
SPORT AND LEISURE-TIME
PHYSICAL ACTIVITY***

19. How much time did you usually spend on one of those days doing **moderate** physical activities inside your home?

_____ **hours per day**
_____ **minutes per day**

PART 4: RECREATION, SPORT, AND LEISURE-TIME PHYSICAL ACTIVITY

This section is about all the physical activities that you did in the **last 7 days** solely for recreation, sport, exercise or leisure. Please do not include any activities you have already mentioned.

20. Not counting any walking you have already mentioned, during the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **in your leisure time**?

_____ **days per week**

☐

No walking in leisure time



Skip to question 22

21. How much time did you usually spend on one of those days **walking** in your leisure time?

_____ **hours per day**
_____ **minutes per day**

22. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like aerobics, running, fast bicycling, or fast swimming **in your leisure time**?

_____ **days per week**

☐

No vigorous activity in leisure time



Skip to question 24

23. How much time did you usually spend on one of those days doing **vigorous** physical activities in your leisure time?
- _____ hours per day
_____ minutes per day
24. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like bicycling at a regular pace, swimming at a regular pace, and doubles tennis **in your leisure time**?
- _____ days per week
- ☐ No moderate activity in leisure time → **Skip to PART 5: TIME SPENT SITTING**
25. How much time did you usually spend on one of those days doing **moderate** physical activities in your leisure time?
- _____ hours per day
_____ minutes per day

PART 5: TIME SPENT SITTING

The last questions are about the time you spend sitting while at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading or sitting or lying down to watch television. Do not include any time spent sitting in a motor vehicle that you have already told me about.

26. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekday**?
- _____ hours per day
_____ minutes per day
27. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekend day**?
- _____ hours per day
_____ minutes per day

This is the end of the questionnaire, thank you for participating.

Appendix P: Par-Q+

2017 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	YES	NO
1) Has your doctor ever said that you have a heart condition ☐ OR high blood pressure ☐ ?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, OR when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness OR have you lost consciousness in the last 12 months? Please answer NO if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? PLEASE LIST CONDITION(S) HERE: _____	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? PLEASE LIST CONDITION(S) AND MEDICATIONS HERE: _____	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer NO if you had a problem in the past, but it <i>does not limit your current ability</i> to be physically active. PLEASE LIST CONDITION(S) HERE: _____	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

 **If you answered NO to all of the questions above, you are cleared for physical activity. Go to Page 4 to sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.**

-  Start becoming much more physically active – start slowly and build up gradually.
-  Follow International Physical Activity Guidelines for your age (www.who.int/dietphysicalactivity/en/).
-  You may take part in a health and fitness appraisal.
-  If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
-  If you have any further questions, contact a qualified exercise professional.

 **If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.**

Delay becoming more active if:

-  You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
-  You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at www.eparmedx.com before becoming more physically active.
-  Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.



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FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?		
If the above condition(s) is/are present, answer questions 1a-1c		If NO ☐ go to question 2
1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	YES ☐ NO ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	YES ☐ NO ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	YES ☐ NO ☐
2. Do you currently have Cancer of any kind?		
If the above condition(s) is/are present, answer questions 2a-2b		If NO ☐ go to question 3
2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck?	YES ☐ NO ☐
2b.	Are you currently receiving cancer therapy (such as chemotherapy or radiotherapy)?	YES ☐ NO ☐
3. Do you have a Heart or Cardiovascular Condition? This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm		
If the above condition(s) is/are present, answer questions 3a-3d		If NO ☐ go to question 4
3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	YES ☐ NO ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	YES ☐ NO ☐
3c.	Do you have chronic heart failure?	YES ☐ NO ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	YES ☐ NO ☐
4. Do you have High Blood Pressure?		
If the above condition(s) is/are present, answer questions 4a-4b		If NO ☐ go to question 5
4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	YES ☐ NO ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer YES if you do not know your resting blood pressure)	YES ☐ NO ☐
5. Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes		
If the above condition(s) is/are present, answer questions 5a-5e		If NO ☐ go to question 6
5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	YES ☐ NO ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	YES ☐ NO ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, OR the sensation in your toes and feet?	YES ☐ NO ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	YES ☐ NO ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	YES ☐ NO ☐

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6. Do you have any Mental Health Problems or Learning Difficulties? *This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome*
If the above condition(s) is/are present, answer questions 6a-6b If **NO** ☐ go to question 7

6a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) YES ☐ NO ☐

6b. Do you have Down Syndrome **AND** back problems affecting nerves or muscles? YES ☐ NO ☐

7. Do you have a Respiratory Disease? *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure*
If the above condition(s) is/are present, answer questions 7a-7d If **NO** ☐ go to question 8

7a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) YES ☐ NO ☐

7b. Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy? YES ☐ NO ☐

7c. If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week? YES ☐ NO ☐

7d. Has your doctor ever said you have high blood pressure in the blood vessels of your lungs? YES ☐ NO ☐

8. Do you have a Spinal Cord Injury? *This includes Tetraplegia and Paraplegia*
If the above condition(s) is/are present, answer questions 8a-8c If **NO** ☐ go to question 9

8a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) YES ☐ NO ☐

8b. Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting? YES ☐ NO ☐

8c. Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)? YES ☐ NO ☐

9. Have you had a Stroke? *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*
If the above condition(s) is/are present, answer questions 9a-9c If **NO** ☐ go to question 10

9a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) YES ☐ NO ☐

9b. Do you have any impairment in walking or mobility? YES ☐ NO ☐

9c. Have you experienced a stroke or impairment in nerves or muscles in the past 6 months? YES ☐ NO ☐

10. Do you have any other medical condition not listed above or do you have two or more medical conditions?
If you have other medical conditions, answer questions 10a-10c If **NO** ☐ read the Page 4 recommendations

10a. Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months? YES ☐ NO ☐

10b. Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)? YES ☐ NO ☐

10c. Do you currently live with two or more medical conditions? YES ☐ NO ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: _____

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.



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If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.



If you answered YES to one or more of the follow-up questions about your medical condition:

You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+** at www.eparmedx.com and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.



Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at www.eparmedx.com before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that the Trustee maintains the privacy of the information and does not misuse or wrongfully disclose such information.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

For more information, please contact

**www.eparmedx.com
Email: eparmedx@gmail.com**

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Appendix Q: Original article included in Chapter 3



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CLINICAL ARTICLE



Differences in pelvic floor muscle morphology and function between female runners with and without running-induced stress urinary incontinence

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Abstract

Objective: To investigate the differences in pelvic floor muscle (PFM) morphology and function between female runners with and without running-induced stress urinary incontinence (RI-SUI).

Design: This was a cross-sectional, observational study.

Methods: Experienced female runners were recruited into two groups: runners who regularly experience RI-SUI ($n = 19$) and runners who do not ($n = 20$). Active and passive pelvic floor muscle (PFM) properties were assessed using intravaginal dynamometry during maximal voluntary contractions (MVC) and during passive tissue elongation. The morphology of the urethra and PFM was assessed using 2D and 3D transperineal ultrasound imaging. Independent t tests or Mann-Whitney U were used as appropriate to test group differences on all study outcomes, and Cohen's d effect sizes were calculated.

Results: The rate of force development during the MVC was significantly higher in participants reporting RI-SUI ($p \leq 0.05$) and conversely, significantly lower during passive elongation of the PFMs ($p \leq 0.05$) compared to runners with no history of leakage. Concurrently, the extent of bladder neck elevation between rest and maximum voluntary activation was significantly higher among those with RI-SUI compared to those without. Although not significant, small to moderate effect sizes were observed for other outcomes—active force outcomes measured during MVC tended to be higher in runners with RI-SUI, while passive force outcomes measured during passive tissue elongation tended to be lower. The cross-sectional area of the urethral wall and the area of the levator hiatus tended to be larger in runners with RI-SUI compared to those without.

Conclusion: Runners who experience RI-SUI demonstrate better PFM contractile function but lower passive support when compared to their continent counterparts.

[Correction added on 22 September 2023, after first online publication: The location of the authors' affiliation has been corrected in this version.]

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KEYWORDS

dynamometry, morphology, pelvic floor, running, ultrasound, urinary incontinence

1 | INTRODUCTION

Recent systematic reviews and meta-analyses have reported on the concerning high prevalence of urinary incontinence (UI) in females from various demographic groups (nulliparous/parous, adolescents/adults) doing a wide range of physical activities,^{1–4} with prevalence reaching 44% among females who perform high-impact sports and activities such as running.² The most commonly reported urinary tract symptom among female athletes is described as stress urinary incontinence (SUI),² which is characterized by involuntary urine leakage experienced during exertion.⁵ Urine leakage experienced during physical activity is a substantial barrier to exercise and up to one in two females limit and restrict the intensity of their physical activity because of urinary tract symptoms.⁶ This is problematic given that running is an accessible, and popular form of physical activity that is also an integral component of many other athletic activities (triathlon, aerobics, CrossFit®, etc).

Some females with SUI primarily or only leak urine when they exercise—and this form of incontinence is poorly understood. As with SUI in the overall population, multifactorial components such as neuromuscular damage and structural damage to the urethra, bladder neck, and the levator ani muscles (PFMs) as well as their associated connective tissues are likely implicated.⁷ Only a handful of studies have investigated the pelvic floor properties between athletes with and without symptoms of athletic incontinence. While one cross-sectional study reported no significant difference in PFM strength nor endurance between continent runners and runners with SUI,⁸ another one found that nulliparous athletes with symptoms of SUI and who practiced a variety of sports, including running, had significantly higher PFM strength than athletes who did not leak urine.⁹ In another study involving a small sample of nulliparous football players, a sport that requires running, incontinent females presented with thicker levator ani muscles at the level of the mid vagina, but no differences were found in the extent of displacement of the pubovisceral muscle during maximal voluntary contractions.¹⁰ They also found no differences in PFM strength between the athletes with and without urinary incontinence.¹⁰ Overall, results from these studies suggest that adaptative changes may impact the morphology and the function of the PFMs among incontinent athletes, but that the observed

changes may depend on the activities performed or on demographic characteristics.

Since running-induced stress urinary incontinence (RI-SUI) is a key reason why women abandon the very physical exercise that is necessary to maintain or improve their physical and mental health and quality of life,⁶ it is imperative that we better understand the specific pathophysiology of urine leakage during this activity. To our knowledge, no study has concurrently investigated both the morphologic and mechanical differences in the pelvic floor structures between runners who experience athletic incontinence and those who do not. The aim of this study was to investigate differences in pelvic floor morphology and function between female runners who do and do not regularly experience SUI while they run, with a view to improving how RI-SUI in female runners is prevented and managed. We hypothesized that females with RI-SUI would exhibit differences in pelvic morphology and levator ani function when compared to continent runners, shedding light on the pathophysiology of RI-SUI.

2 | MATERIALS AND METHODS**2.1 | Design**

This cross-sectional, observational case-control study received approval from the local institutional research ethics board. Data collection occurred between June of 2019 and March of 2021, with a gap between March of 2020 and January of 2021 due to laboratory closures related to the COVID-19 pandemic. Using pilot data from the area of the levator hiatus at rest in standing recorded using transperineal ultrasound imaging (USI) from four runners with SUI (mean 20.8 cm²; SD 6.21 cm²) and eight without SUI (mean 15.99 cm²; SD 2.32 cm²), an a priori two-tailed power calculation using G*Power (version 3.0.10; $\alpha = 0.05$; $\beta = 0.80$) estimated that a minimum of 16 runners per group would be necessary to detect between-group differences.

2.2 | Participants

Runners aged 18 years and older who had female reproductive organs and no known risk factors related to physical activity, as determined by the administration of the Physical Activity Readiness Questionnaire for

Everyone (PAR-Q+)¹¹ were recruited from the local community through local running groups and physiotherapy clinics. To be eligible, volunteers had to train by running at least 5 km in less than 50 min at least twice per week and average more than 10 km of distance per week, having done so for at least 1 year. Runners were recruited into two cohorts: those who regularly (≥ 1 per week) experienced SUI while running, and those who did not. Runners who reported leaking at least two to five times per month while using mitigation strategies (voiding their bladder before/during the run, running slower, avoiding hills, etc.) to avoid leakage were included if they leaked more than once per week when not using these strategies. Participants who reported sporadic episodes of urinary urgency during running, without associated leakage, were not excluded. Runners were excluded if they presented with a history of urogenital surgery or neurological disorders, if they reported symptoms of low energy deficiency as measured by the Low Energy Availability in Females Questionnaire (LEAF-Q),¹² if they were pregnant or if they had delivered a baby within the previous year, if they had a pelvic organ prolapse that was caudal to the hymen on a maximal Valsalva maneuver (MVM) performed in a standing position, or if they experienced pelvic pain to the extent that they were not able to undergo a regular gynaecologic examination. They were also excluded if they reported leakage related to urinary urgency during running. After providing written informed consent, all eligible participants provided demographic information including age, parity, obstetrical history (i.e. vaginal vs. Caesarean section, use of forceps) and menopausal status, and were asked to complete the International Consultation on Incontinence-Female Lower Urinary Tract Symptoms Long Form module (ICIQ-FLUTS),¹³ the Anal Incontinence Symptoms and Quality of Life module (ICIQ-B),¹⁴ the vaginal symptoms module (ICIQ-VS)¹⁵ the and the International Physical Activity Questionnaire (IPAQ).¹⁶

2.3 | Laboratory assessment

The laboratory assessment was performed by the main researcher, who is a registered physiotherapist trained as a pelvic health physiotherapist with over 5 years of experience. Height, weight, and waist-hip ratio were recorded using standardized techniques. Next, participants underwent an intravaginal examination of their pelvic floor in supine using standard bi-digital palpation techniques.¹⁷ If the participant was unable to perform a proper maximal voluntary contraction (MVC) of their PFM, they received instructions and tactile feedback to

ensure that a proper contraction could be performed before any data collection. Once a correct PFM contraction could be performed, the participant was also shown and provided with feedback on how to perform a maximal Valsalva manoeuvre (MVM). For the purposes of this study, Valsalva was defined as a bearing down manoeuvre with concomitant relaxation and caudal movement of the pelvic floor and perineum.

Once ready, the participants underwent a 2D and 3D B-mode ultrasound imaging (USI) evaluation of their pelvis using a GE Voluson S6 system (General Electric). The study physiotherapist first used trans-abdominal ultrasound imaging to standardize estimated bladder volume between 100 and 200 mL. If bladder volume was under 100 mL, the participant was asked to drink a small amount of water and to wait 20 min; if it was over 200 mL, the participant was asked to void a small amount to bring the volume within a range of 100–200 mL. Once the target bladder volume was reached, in a standardized supine position with the knees bent approximately to 90°, three static 3D volumes of the full length of the urethra were collected using a RIC5-9A-RS endoprobe (4–9 MHz; GE Healthcare Ltd) placed at the urethral meatus.^{18,19} Next, participants assumed a standardized standing position with their feet shoulder width apart, their knees slightly flexed, and their pelvis just touching an examination table posteriorly to limit postural sway. A series of 2D sagittal plane images and 3D volumes were acquired using a RAB6-RS (2–5 MHz; GE Healthcare Ltd) 3D curvilinear probe placed transperineally. A static 3D volume was acquired of the levator hiatus in quiet standing and dynamic volumes (4D) were acquired while the participant performed the MVM three times.^{20–22} 2D ultrasound videos were then recorded during MVM, and MVCs of the pelvic floor muscles (PFMs)^{23,24} each performed three times. 2D videos were processed offline using a custom MATLAB code (R2020a) and 3D volumes were processed offline using 4D View® software (GE Healthcare Ltd).

While remaining in a standing position, participants were instrumented with an automated, servo-controlled intravaginal dynamometer. The closed arms were inserted into the vagina, then the arms were opened to an antero-posterior (AP) diameter of 35 mm. Participants were asked to perform three repetitions of the MVC while forces in the mid-sagittal plane were recorded in Newtons. The participant then returned to the supine position. The dynamometer arms were once again inserted into the vagina, and passive forces were recorded while the AP diameter of the dynamometer arms moved from 15 to 40 mm at a constant speed of 50 mm/s. Pelvic floor muscle elongation was held at the maximum (40 mm) diameter for 7 s to evaluate the stress

relaxation response before the arms returned to the closed position. If the participant contracted their PFMs during passive elongation, which was evident as a sharp increase in force on the display screen, the trial was discarded and was repeated. Three repetitions of passive tissue elongation were performed. The validity and reliability metrics for these measures and all details of the standardized procedures can be found in previous publications.^{25,26}

2.4 | Outcomes

The PFM morphologic outcomes captured by 3D USI included the cross-sectional area (CSA) of the urethral wall at the mid-urethra,^{18,19} the area, antero-posterior (AP) diameter and medio-lateral (ML) diameter of the levator hiatus at rest and on MVM, as well as the difference between these outcomes at rest and at peak MVM.^{20–22} Signs of complete and partial levator avulsion were evaluated using the 3D volumes of the levator plate acquired in standing and the techniques described by Dietz et al.^{27,28} From the 2D USI videos, the bladder neck (BN) height, and levator plate (LP) length at rest, and their relative displacement during the MVC and MVM tasks were measured.^{23,24} Measures of PFM function acquired through dynamometry included baseline force, relative peak force, and rate of force development achieved during each MVC, and static endurance measured as the time before the peak force achieved during the MVC decreased by 35%. Passive tissue forces measured during elongation included baseline force, relative peak resistance to passive stretch, rate of force development (stiffness) during passive elongation,^{25,26} and the stress relaxation coefficient (SRc). Rate of force development was measured as the highest instantaneous slope observed during elongation,^{25,26} while the stress relaxation coefficient was quantified by curve-fitting the data to the equation $y = a \times x^b + c$, where b represents the decay coefficient representative of the SRc; more negative values for SRc reflect greater elasticity.

2.5 | Data analysis

All statistical testing was carried out using IBM SPSS version 28 and $\alpha = 0.05$ was used for all tests. All outcomes were tested for normality using the Shapiro–Wilks test, and parametric (t test) or non-parametric (Mann–Whitney U) analyses were used as appropriate to test group differences between runners with and without RI-SUI, while χ^2 was used to analyze group differences in dichotomous variables. Due to the

exploratory nature of the study, $\alpha = 0.05$ was not adjusted based on multiple comparisons. Cohen's d values were calculated for each outcome; $d < 0.2$ were considered small, $0.2 \leq d < 0.5$ were considered moderate, and $d \geq 0.8$ were considered large.²⁹

3 | RESULTS

3.1 | Sample demographic information

Sixty-nine female runners were screened, of which, 59 were eligible and 39 completed the laboratory assessment. Among the 20 potential participants who were deemed eligible but who did not participate, $n = 13$ did not respond to follow-up email after screening, $n = 2$ declined to participate because of the COVID-19 pandemic, $n = 4$ had temporarily stopped running after the screening session or were too busy, and $n = 1$ had a pelvic organ prolapse beyond the hymen noted on examination ($n = 1$). Twenty runners were included in the control group (i.e., no urine leakage during running), while 19 were cases (i.e., SUI ≥ 1 /week during running). The groups were similar in terms of demographic outcomes (Table 1), however, the controls were slightly younger than the cases ($p = 0.01$). The ICIQ-FLUTS total score was significantly higher ($p \leq 0.001$) in participants who experienced SUI during running, which was driven by the results from the Urinary Incontinence subscale. Although an effort was made to recruit runners who exclusively leaked urine during running, most reported leaking during other activities of daily living such as during coughing and sneezing at a minimum of a few times per year.

3.2 | Dynamometry outcomes

The results for the PFM function as measured using intravaginal dynamometry are presented in Figure 1. Three participants had to repeat one passive elongation trial each due to PFM contraction. During MVC, compared to runners with no RI-SUI, the rate of force development was higher in those with RI-SUI ($p \leq 0.05$, $d = 0.40$). Conversely, during passive tissue elongation, the rate of force development was lower in those with RI-SUI ($p \leq 0.05$, $d = 0.80$). Active force outcomes measured during the MVC (relative peak force and endurance) tended to be higher in participants with RI-SUI ($d = 0.45$ and $d = 40$, respectively), while relative peak force during passive tissue elongation tended to be lower ($d = 0.49$), however these were not statistically significant. Baseline forces and SRc had small effect sizes ($d = 0.01$ and $d = 0.17$ respectively).

TABLE 1 Demographic information.

	No SUI with running (<i>n</i> = 20)		SUI with running (<i>n</i> = 19)			Significance
	Mean/ <i>n</i>	SD/%	Mean/ <i>n</i>	SD/%		
Age (years)	36.2	7.9	43.9	10.6	a	0.01*
SUI with other activities (<i>n</i> , %)	8	40%	16	84%	b	$\chi^2(1) = 8.046, p = 0.005^*$
BMI (kg/m ²)	22.0	2.3	24.2	5.0	a	0.184
Waist to hip ratio	0.8	0.1	0.8	0.1	a	0.550
Parous (<i>n</i> , %)	6	30%	11	58%	b	$\chi^2(1) = 3.083, p = 0.079$
Primipara (<i>n</i> , %)	3	15%	1	5%	b	$\chi^2(1) = 1.004, p = 0.316$
Multipara (<i>n</i> , %)	3	15%	10	53%	b	$\chi^2(1) = 6.209, p = 0.013^*$
Use of forceps (<i>n</i> , %)	1	5%	3	16%	b	$\chi^2(1) = 1.232, p = 0.267$
Use of suction (<i>n</i> , %)	0	0%	3	16%	b	$\chi^2(1) = 3.421, p = 0.064$
Menopause (<i>n</i> , %)	1	5%	3	16%	b	$\chi^2(1) = 1.232, p = 0.267$
Pelvic floor muscle training (<i>n</i> , %)	2	10%	6	32%	b	$\chi^2(1) = 2.783, p = 0.095$
Signs of complete avulsion (<i>n</i> , %)	1	5%	0	0%	b	$\chi^2(1) = 0.975, p = 0.323$
Signs of partial avulsion (<i>n</i> , %)	3	15%	4	20%	b	$\chi^2(1) = 0.242, p = 0.622$
ICIQ-FLUTS total score (/48)	5.0	4.2	9.9	3.3	a	<0.001*
ICIQ-FLUTS F (/16)	2.7	2.2	3.3	2.1	a	0.351
ICIQ-FLUTS V (/12)	0.7	2.0	0.8	1.3	a	0.322
ICIQ-FLUTS I (/20)	1.7	2.0	5.8	2.3	a	<0.001*
ICIQ-bowel total score (1–75)	7.9	6.3	9.3	7.5	a	0.296
ICIQ-bowel pattern (1–21)	3.2	1.4	3.8	1.4	a	0.235
ICIQ-bowel control (/28)	2.2	2.7	2.8	3.3	a	0.365
ICIQ-bowel quality of life (/26)	2.5	4.6	2.7	3.6	a	0.513
ICIQ-vaginal symptoms (/53)	2.7	3.2	4.4	6.0	a	0.461
ICIQ-sexual Matters (/58)	6.9	9.8	3.8	7.9	a	0.478
ICIQ-vaginal quality of life (/10)	0.7	1.3	0.7	1.1	a	0.923
IPAQ total activity (MET-minutes/week)	3294.7	2122.5	5497.0	8089.7	a	0.687
IPAQ subtotal vigorous activities (MET-minutes/week)	1278.0	918.2	1708.9	3099.0	a	0.531

Note: Values are presented as mean $\pm$ standard deviation (SD) or the frequency and percentage. Significant differences ($\alpha = \leq 0.05$) between groups are indicated by * and are in bold. Significance represents the level for between-group differences from the Mann-Whitney *U* test^a and the χ^2 test^b. $\pm$ Caesarean deliveries were coded as nulliparous.

Abbreviations: BMI, body mass index; ICIQ-FLUTS, International Consultation on Incontinence-Female Lower Urinary Tract Symptoms Long Form module; IPAQ, International Physical Activity Questionnaire; MET, metabolic equivalent of task; SUI, stress urinary incontinence.

3.3 | Ultrasound imaging outcomes

3.3.1 | 3D USI outcomes

PFM outcomes measured from 3D USI are presented in Figure 2. The CSA of the urethral wall tended to be larger

among those with RI-SUI ($d = 0.50$), while the area and diameters of the levator hiatus at rest and during peak MVM also tended to be larger ($0.35 < d < 0.63$), but these trends were not significant. The change in levator hiatus area, and its associated AP and ML diameters during the MVM was not different between the groups ($0.06 < d < 0.14$).

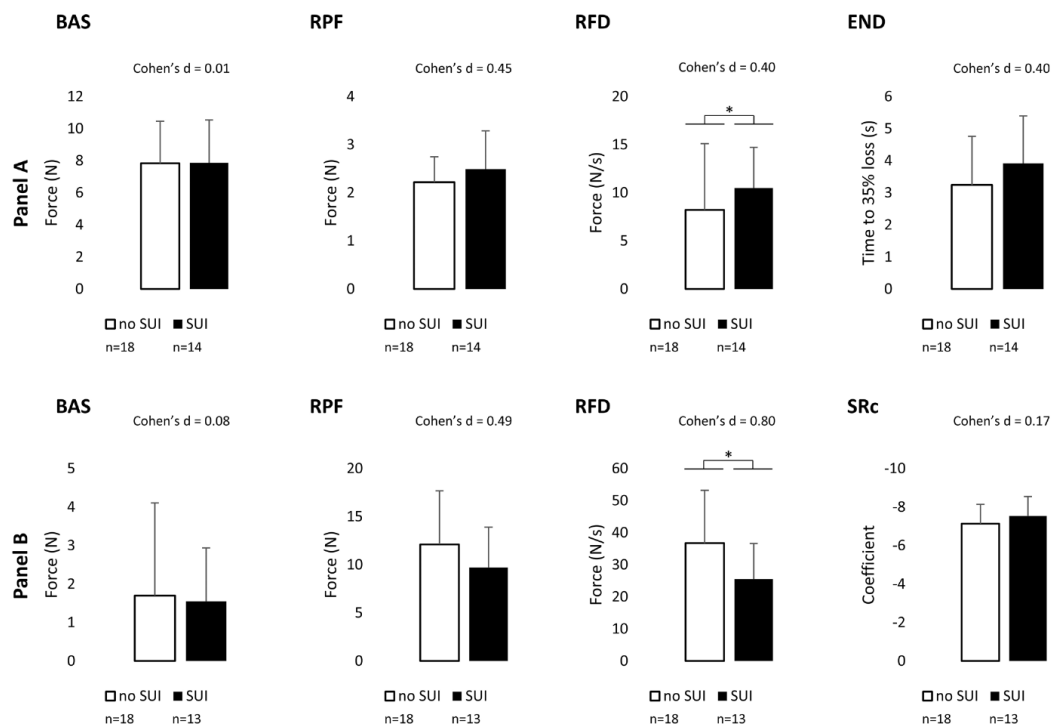


FIGURE 1 Pelvic floor muscle function as measured by intravaginal dynamometry is presented for a maximal voluntary contraction (MVC) in (A) and during passive tissue elongation in (B) for runners without (in white) and with (in black) running-induced stress urinary incontinence. The mean active force in Newtons (N) with the standard deviations are presented for the baseline values and the relative peak force. Endurance is presented as the time in seconds taken to lose 35% of the force after the peak force was reached during the MVC. The rate of force development in Newtons per seconds (N/s) is presented for both MVC and the passive tissue elongation, and the stress relaxation response was measured by the stress relaxation coefficient during the passive tissue elongation. The * indicates a significant difference ($\alpha \leq 0.05$) between groups. Cohen's *d* values are presented for each outcome. Missing data was due to equipment malfunction.

3.3.2 | 2D USI outcomes

PFM outcomes measured from dynamic 2D USI are presented in Figure 3. During MVC, BN height increased more among those with RI-SUI than those without ($p \leq 0.05$, $d = 0.50$). No other 2D USI outcomes were significantly different between the groups, although the resting position of the BN tended to be lower among those with RI-SUI ($d = 0.50$). While not significant, the BN tended to sit more caudally at peak MVC ($d = 0.27$) and peak MVM ($d = 0.28$) among those with RI-SUI compared to their continent counterparts. A similar trend was observed for LP length during MVC. The LP length did not differ between groups at rest nor during peak MVC or MVM ($0.00 < d < 0.17$), however the runners with RI-SUI tended to generate more shortening of their levator plate during the MVC ($d = 0.29$) and less elongation of their levator plate

during the MVM ($d = 0.21$) than their continent counterparts.

4 | DISCUSSION

To our knowledge, no published studies have reported on PFM morphology and function measured concurrently using USI and intravaginal dynamometry to uncover potential adaptations in pelvic floor support and function associated with RI-SUI. The results of this study point to adaptations including improved contractile ability of the PFMs, reflected by more rapid force development, or power, in the antero-posterior direction, greater lift of the BN during PFM MVC and greater thickness of the urethral wall, as well as less effective passive support reflected by slower passive force development, or stiffness, during elongation of the paravaginal tissues,

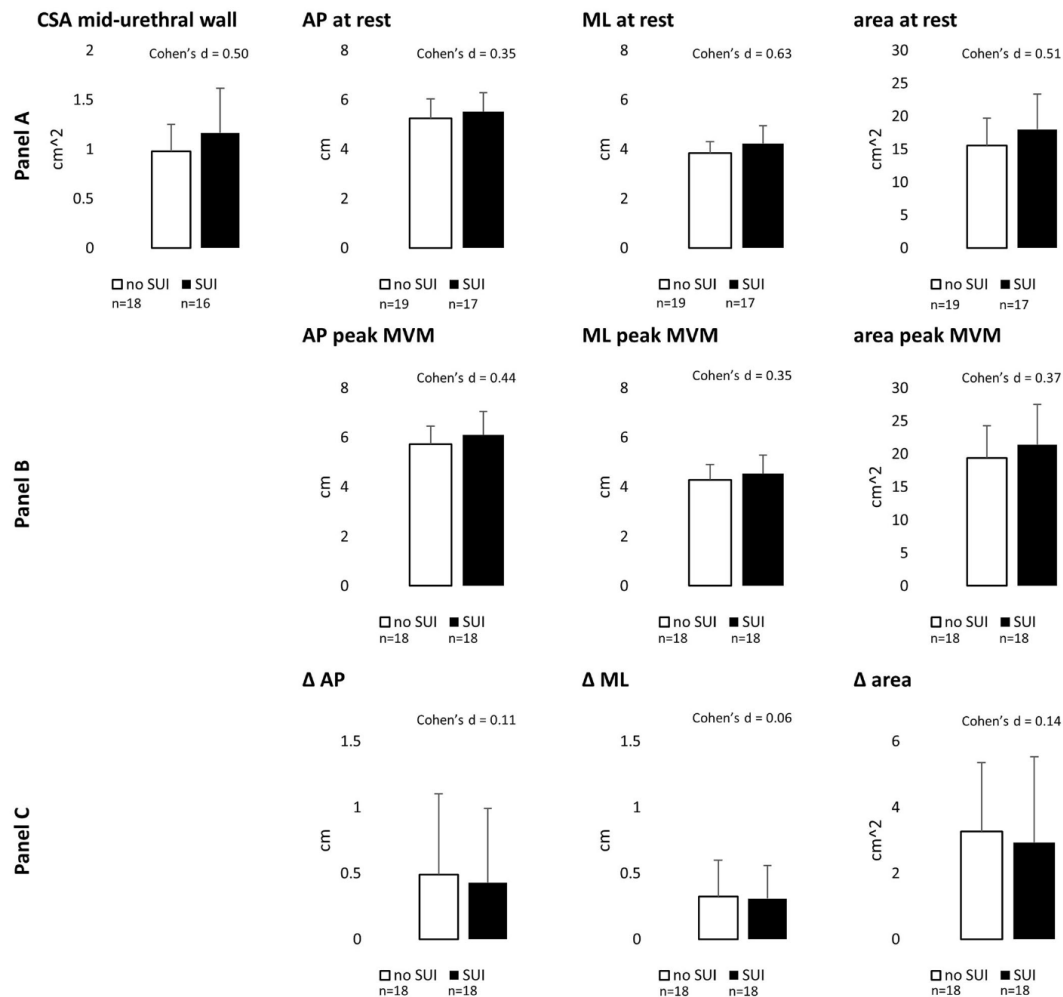


FIGURE 2 Mean pelvic floor morphology outcomes obtained from the 3D ultrasound imaging in standing are presented for runners without (in white) and with (in black) running-induced urine leakage. The standard deviations are presented for each outcome as error bars. The mean cross-sectional area (CSA) of the urethral wall in centimeters square, as well as the anteroposterior (AP) diameter, the mediolateral (ML) diameter in centimeters, and the area of the levator hiatus in centimetres square are presented both at rest (A) and during peak maximal Valsalva manoeuvre (MVM) (B). The difference (Δ) between the initial and end position during the MVM is presented in (C). The * indicates a significant difference ($\alpha \leq 0.05$) between groups. Cohen's d values are presented for each outcome. Missing data was due to poor volume quality.

and lower BN height at rest. Because the runners with and without RI-SUI had similar running experience and volume, these adaptations do not appear to be solely related to cumulative loading of the pelvic support structures as a result of running. Greater PFM power might reflect a compensation for the loss of tissue stiffness and urethral support observed among the

runners who leak urine but not among the continent runners.

The results of this study are generalizable to experienced female runners who run a minimum of 10 km/week and who have done so for at least 1 year. Although our sample consisted of runners who run as a main form of physical activity, they can be reasonably

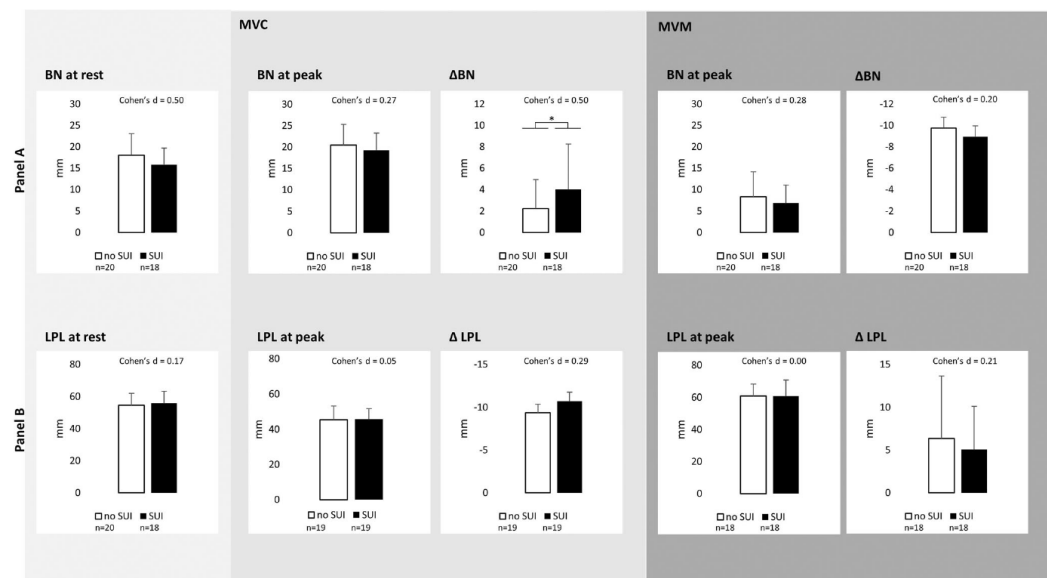


FIGURE 3 Mean pelvic floor morphology outcomes obtained from 2D ultrasound imaging in standing are presented for runners without (in white) and with (in black) running-induced leakage. The standard deviations are presented for each outcome as error bars. The bladder neck (BN) position at rest in millimeters (mm), during peak maximal voluntary contraction (MVC) and during peak maximal Valsalva maneuver (MVM) are presented in (A), as well as the difference (Δ) between the initial and end position during both tasks. The levator plate length (LPL) measurements for both tasks are presented in (B). The * indicates a significant difference ($\alpha \leq 0.05$) between groups. Cohen's d values are presented for each outcome. For simplicity, the figure for BN at rest is pulled from the average of three trials before the MVM trials started. However, the difference (Δ) between rest and peak position during the MVC are presented for that task—this decision was made to limit the number of figures. Missing data was due to poor image quality.

extrapolated to other physically active females who run similar volumes as part of other physical activities. Our sample consisted of a balanced proportion of nulliparous and parous middle-aged (28–66 years) premenopausal (45 of 49) runners that were mostly Caucasian (48 of 49), and as such, the results are to be interpreted within this context.

4.1 | Intravaginal dynamometry

Results from this study provide primary evidence that runners who experience RI-SUI demonstrate better capacity to rapidly develop contractile force of their PFM during MVC. Although other measures did not reach statistical significance, the relative peak force observed during the MVC and endurance were also higher in the SUI group and had moderate effect sizes when compared to the runners who do not leak urine. While these differences may be the result of adaptations to counteract urine leakage, the mechanisms underlying

these changes remain unknown. A systematic review investigating PFM activity during impact in continent and incontinent females suggested those with SUI demonstrate delayed PFM activity,³⁰ however, the EMG methods used to measure PFM activation during high-impact may be invalid due to the high likelihood of crosstalk and motion artifact contamination.^{7,31} Although the current findings appear contradictory, it is plausible that the delay in PFM activation is related to reduced stiffness in the PFMs among those who experience SUI during running.³² In turn, the PFMs may adapt to this delay by increasing their ability to generate force more rapidly, as was observed here. Changes in fiber type composition and motor unit discharge rate could also play a role,³² however this was not assessed in the present study. The trends toward higher relative peak force and endurance among the runners with RI-SUI differ from those by de Melo Silva et al.⁸ who reported lower vaginal squeeze pressures and lower endurance among runners with incontinence. While the effect sizes were moderate in this study, these

results were not statistically significant in either study. The discrepancy in results may be related to the difference in measurement tools; de Melo Silva et al.⁸ used perineometry in supine to evaluate the PFM squeeze pressure and endurance whereas we used dynamometry in standing. We chose to measure PFM forces in standing to observe PFM function in a gravity-dependent position, which is a more accurate reflection of how the pelvic floor is loaded during running. Additionally, six runners with RI-SUI mentioned engaging in ongoing PFM training, while only two continent runners reported doing so. Although the difference was not significant between cohorts, it is possible that PFM training among runners with RI-SUI may have had a positive impact on their PFM function, including strength and power.

The rate of force development during passive elongation (i.e., stiffness) of the levator ani was lower in runners with RI-SUI compared to their continent counterparts. While it was not significant, the relative peak force at the maximal opening of 40 mm was also lower in the runners with RI-SUI and had a moderate effect size. These results suggest that strain of the PFMs and surrounding connective tissues may be a mechanism that contributes to RI-SUI. To our knowledge, this is the first study to have used intravaginal dynamometry to measure the passive properties of the PFMs in female athletes—therefore, it is not possible to compare these results to other studies. While one study that investigated the passive force values between females with and without SUI during activities of daily living using intravaginal dynamometry found no statistical group difference,³³ another found lower stiffness among those with SUI.³⁴ Differences in aperture, speed of opening, protocols, and sample characteristics likely contributed to these different results. A standardized approach to the measurement of passive tissue properties is needed.

The MVC force outcomes obtained from the dynamometry measurements support the theory that runners with leakage, consciously or unconsciously, train their PFMs during running by contracting them to prevent leakage, inducing a training effect relative to continent runners.³⁵ While it is plausible that runners who leak urine compensate for lower stiffness in their PFMs and other connective tissue supports, this strategy was not effective, since this sample still leaked urine during running. For this reason, it appears that reduced stiffness of the pelvic floor connective tissues might be the predominant factor driving RI-SUI symptoms. Greater adaptations to PFM strength and power may be needed to counteract strain in the passive structures. Indeed, a recent systematic review concluded that athletes with

incontinence benefit from PFM training, which decreases the frequency and the amount of leakage,³⁶ yet it does not eliminate it.

4.2 | Ultrasound imaging

The CSA of the urethral wall, measured using USI, reflects the thickness of the striated urethral sphincter and the connective tissues of the outer wall and tended to be larger among participants with RI-SUI than those without SUI, with a moderate effect size. While it is impossible to compare these results to other studies involving female athletes, two previous studies reported that women who experienced SUI during activities of daily living had smaller cross-sectional area of the urethral wall compared to continent participants.^{37,38} We hypothesize that female athletes who leak urine may, as with their levator ani muscles, contract the striated urethral sphincter to enhance urinary continence control as a means of compensating for a loss of passive support of the pelvic structures. This hypothesis would need to be investigated through other measures, such as urodynamic assessment.

While most published research reports pelvic floor morphology as observed in a supine position, we chose to measure the area of the levator hiatus and the height of the BN in standing to observe its morphology in a gravity-dependent position, which is a more accurate reflection of the normal position of the pelvic structures during gait-based activities. Although moderate effect sizes suggested the levator hiatus is larger at rest among those with RI-SUI compared to continent controls, these findings did not reach significance; a larger sample size might achieve significance. Again, while 3D USI has not previously been used in this population, studies investigating SUI in the general population report similar outcomes to the ones from this study, suggesting that loss of passive support plays a role in the pathophysiology of SUI.⁷

Dynamic 2D USI was also captured in standing to evaluate the effect of MVC and MVM on changes in pelvic morphology in a functional position. Two findings are of particular note. First, the BN height at rest in standing was lower among those with RI-SUI compared to the control group, suggesting that, consistent with the dynamometry findings, the bladder and urethral support structures may be strained in runners who experience SUI. Second, during the MVC, the runners with RI-SUI elevated their BN more than continent runners. Again, consistent with the dynamometry measures, this may reflect a compensatory mechanism to provide more support to the urethra and may assist with externally

compressing it to prevent leakage during running. Although it was not significant, a similar trend was observed in the LP length—albeit with a small effect size.

While it is not yet understood why and how changes in the pelvic floor morphology and function occur in runners with leakage as opposed to continent runners with similar running experience, running volume, and parity, the findings of this study support the following two hypotheses: (1) that females with RI-SUI experience greater pelvic floor loading during running activities (due to higher intra-abdominal pressure or gravitational loading) which results in strain of the pelvic support structures, and/or (2) that females with RI-SUI have less effective pelvic organ support for reasons outside of cumulative loading induced by running. Further research is needed to test these hypotheses.

4.3 | Limitations

Limitations of this study include the inherent recruitment bias of cross-sectional designs—the female runners who attended the laboratory assessment were likely interested in their pelvic health a priori. In addition, because 23% of participants with urinary symptoms will stop engaging in running as a result of their condition⁶—our sample may be biased toward those with less severe symptoms because those who participated had not stopped running due to UI. A group of female runners who are contemplating or have recently stopped running due to UI should be recruited to evaluate the presence and the extent of any differences in the PFM function and morphology compared to those who participated in the current study.

Vaginal birth is acknowledged as a risk factor for UI and it is likely to influence the structure and function of the PFMs. Despite attempts to match the groups on parity during the recruitment process, there were more multiparous female runners among those with RI-SUI compared to those without. Despite this difference, there were equal numbers of participants in each group ($n = 4$) who presented with levator avulsion, yet other parity-related changes to the pelvic floor may have influenced the outcomes of this study. Because the samples were not matched in terms of parity, we ran a post hoc analysis looking at nulliparous runners only to determine whether parity may have influenced the findings. Among nulliparous runners, the statistical outcomes followed the same trends as observed in the overall sample. For example, on dynamometry, the nulliparous runners with RI-SUI ($n = 4$) had higher rate of force development during contraction (12.1 vs. 8.7 N/s), yet lower rate of force development during

passive elongation (34.8 vs. 40.7 N/s) than nulliparous runners without RI-SUI ($n = 12$). On USI, the nulliparous runners with RI-SUI ($n = 8$) had a BN position that was significantly lower (15.0 vs. 19.7 mm) than what was observed in nulliparous runners without RI-SUI ($n = 14$). Further research with a larger participant pool is essential to establish the interaction between RI-SUI and parity.

The cross-sectional nature of this study does not allow the results to contribute to the debate regarding the impact of exercise on pelvic floor function, where some advocate that high impact exercise is harmful,³⁹ and others report that the evidence for harm is scant,⁴⁰ and that women should not be discouraged to participate in high intensity training.⁴¹

Lastly, it is important to note that changes in the levator hiatus area measured during the MVM in standing might have been compromised by co-contraction of the PFMs. While both running groups were provided with extensive cueing and feedback using USI on how to perform a proper MVM with concurrent pelvic floor relaxation, consistent with several previous reports,^{42–45} a co-contraction of the pelvic floor was observed in 9 out of 20 continent runners (45%) and in 6 of 19 incontinent runners (32%). While we chose to include the MVM task to measure the extent to which the connective tissues of the pelvic floor experience strain during running, levator ani co-contraction might have limited the caudal movement of the BN and the lengthening of the LP observed in the 2D sagittal imaging, as well as the increase in levator hiatus area, AP diameter and ML diameter during the 3D imaging. These findings should therefore be interpreted with caution.

5 | CONCLUSION

The novel methods used in this study add to our understanding of the pathophysiology of RI-SUI. The significant changes and moderate effect sizes found in the active and passive properties of the pelvic tissues suggest that runners with RI-SUI demonstrate improved PFM function (capacity to lift cranially, and power of vaginal closure force, thicker urethral wall) and impaired pelvic organ support (BN height in standing and stiffness in the levator ani muscle). While we cannot be certain that the improvement in PFM contractile abilities are compensatory, we hypothesize that this is the case. Future research should aim to investigate the impact of an acute bout of running of the active and passive properties of the pelvic floor, should quantify the extent of pelvic floor loading

experienced by the pelvic floor during running, and should apply a longitudinal study design to appreciate the time course and progression of changes observed in the contractile and stiffness characteristics of the pelvic floor.

AUTHOR CONTRIBUTIONS

Marie-Eve Berube and Linda McLean were fully involved in the conceptualization, in the design of the study, and in the preparation of this manuscript. Under the mentorship of Dr. McLean, Ms. Berube was primarily responsible for collecting data and preparing the original draft. Both authors contributed to the revision process and provided final approval before this submission.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request. All data relevant to the study are included in the article or are available as Supporting Information.

ETHICS STATEMENT

The study protocol was approved by the Research Ethics Board of the University of Ottawa. The participants provided informed consent before participating in the protocol.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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Appendix R: Original article included in Chapter 4

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ORIGINAL ARTICLE



The acute effects of running on pelvic floor morphology and function in runners with and without running-induced stress urinary incontinence

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Abstract

Introduction and hypothesis The aim of this study was to examine the impact of a single running session on pelvic floor morphology and function in female runners, and to compare those with and without running-induced stress urinary incontinence (RI-SUI).

Methods This cross-sectional, observational study involved two groups: female runners who regularly experienced RI-SUI ($n = 19$) and runners who did not ($n = 20$). Pelvic floor muscle (PFM) properties were assessed using intravaginal dynamometry during maximal voluntary contractions (MVC) and during passive tissue elongation. The morphology of the pelvic floor was assessed at rest, during MVC and during maximal Valsalva maneuver (MVM) using 2D and 3D transperineal ultrasound imaging before and after a running protocol. Mixed-effects ANOVA models were used to compare all outcomes between groups and within-groups, including the interaction between group and time. Effect sizes were calculated.

Results No changes in PFM function assessed using intravaginal dynamometry were observed in either group after the run. Significant and large within-group differences were observed on ultrasound imaging. Specifically, the area and antero-posterior diameter of the levator hiatus were larger after the run, the bladder neck height was lower after the run, and the levator plate length was longer after the run ($p \leq 0.05$). At the peak MVM and MVC, the bladder neck height was lower after the run than before the run ($p \leq 0.05$). No between-group differences were observed for any outcomes.

Conclusions Running appears to cause transient strain of the passive tissues of the female pelvic floor in runners both with and without RI-SUI, whereas no concurrent changes are observed in PFM contractile function.

Keywords Dynamometry · Morphology · Pelvic floor · Running · Ultrasound · Urinary incontinence

Abbreviations

AP	Antero-posterior
BN	Bladder neck
LH	Levator hiatus
LP	Levator plate
ML	Medio-lateral
MVM	Maximal Valsalva maneuver
MVC	Maximal voluntary contraction
PFM	Pelvic floor muscle
RI-SUI	Running-induced stress urinary incontinence
SUI	Stress urinary incontinence
USI	Ultrasound imaging

Introduction

Stress urinary incontinence (SUI), the complaint of involuntary urine loss [1] that occurs when the bladder pressure exceeds the urethral capacity to remain closed, is the most commonly reported pelvic floor dysfunction during high-impact activities [2] and can limit females from participating in an active lifestyle [3, 4]. There is ongoing debate in the literature regarding the impact of exercise on pelvic floor function. Whereas some advocate that high-impact exercise is harmful and may induce strain on the structures that provide support [5], the evidence for harm is scant and some researchers encourage females to participate in high-intensity training, noting that risk is low and that exercise may improve pelvic floor support and strength [6]. Both hypotheses are supported by a review [2], which reported that females who engaged in physical activity had a 177% higher risk of reporting urinary incontinence than sedentary

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females, yet concurrently noted that exercise, when done at mild to moderate intensity, was protective of the pelvic floor, decreasing the odds and the risk of experiencing urinary incontinence [7].

As with SUI in the overall population, multiple factors, such as neuromuscular damage and structural damage to the urethra and the levator ani muscles, as well as their associated connective tissues [8, 9], are likely implicated in SUI experienced during athletic activities. Yet repetitive loading of the pelvic floor may, over a bout of exercise, lead to muscle fatigue and/or tissue strain, which additionally contributes to urine leakage during repetitive high-impact activities such as running [9]. Indeed, some researchers have reported that SUI during training occurs mainly during the middle or at the end of training sessions [10].

To our knowledge, no studies have investigated the acute, transient impact of running on pelvic organ support and pelvic floor muscle (PFM) function, or compared these effects between females who experience running-induced stress urinary incontinence (RI-SUI) and those who do not. Such robust biomechanical data are needed to fully understand the acute effects of running on pelvic floor morphology and function. Considering the absence of previous research in this area, the goal of this study was to provide critical insight into the impact of running exposure on pelvic floor morphology and function in female runners. We hypothesized that all runners would demonstrate evidence of levator ani muscle fatigue and a reduction in connective tissue support after the run, and that these changes would be more marked among runners with RI-SUI. The study was developed to generate new knowledge that would contribute to the development of targeted, evidence-based pelvic floor physiotherapy interventions for exercise-induced urine leakage, particularly during running.

Materials and methods

Design

This cross-sectional, observational study received prior approval from the local institutional research ethics board. Data were collected between June 2019 and March 2021, with a pause between March 2020 and January 2021 owing to laboratory closures caused by the COVID-19 pandemic.

Participants

Female runners assigned female at birth, over 18 years of age, and with no known risk factors related to physical activity (as determined by the administration of the Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) [11]) were recruited from the local community through local

running groups and physiotherapy clinics. To meet the eligibility criteria, which were aimed at ensuring that runners had sufficient, regular, and prolonged exposure to high-impact loading of the pelvic floor through running, volunteers were required to run at least 5 km in under 50 min, twice a week, and to have maintained an average running distance over 10 km per week for a minimum of 1 year. Runners were recruited into two groups, intended to be matched by age and parity: runners who frequently experienced SUI (one or more episodes per week) while running and those who did not. Runners with SUI during running who reported using mitigation strategies (voiding their bladder before/during the run, running slower, avoiding hills, etc.) to avoid leakage were included if they leaked more than once per week when not using these strategies and still had a minimum one leakage episode while running per month while using these strategies. Participants were not excluded if they experienced occasional instances of urinary urgency during running without any associated leakage. Runners were excluded if they presented with a history of urogenital surgery or neurological disorders, if they reported symptoms of low energy deficiency as measured by the Low Energy Availability in Females Questionnaire (LEAF-Q) [12], if they were pregnant or if they had delivered a baby within the previous year, if they had a pelvic organ prolapse that was caudal to the hymen on a maximal Valsalva maneuver (MVM) in a standing position, or if they experienced pelvic pain to the extent that they were not able to undergo an intravaginal examination using a speculum. They were also excluded if they reported leakage associated with urgency during running. After providing written informed consent, all eligible participants provided demographic information including age, parity, obstetrical history (i.e., vaginal vs caesarean section, use of forceps or vacuum) and menopausal status, and were asked to complete the International Consultation on Incontinence—Female Lower Urinary Tract Symptoms Long Form module (ICIQ-FLUTS) [13], the Anal Incontinence Symptoms and Quality of Life module (ICIQ-B) [14], the Vaginal Symptoms module (ICIQ-VS) [15], and the International Physical Activity Questionnaire (IPAQ) [16].

Laboratory assessment

The laboratory assessment was performed by a registered physiotherapist trained in pelvic health and with over 5 years of experience in this practice area, who also received over 50 h of training on intravaginal dynamometry and ultrasound imaging, and had over 2 years of experience using these instruments.

The morphology of the PFMs was assessed using 2D and 3D B-mode transperineal ultrasound imaging (USI) via a GE Voluson S6 system (General Electric, Toronto, Canada) with a standardized bladder volume between 100 and 200 mL. In

a standardized standing position, static (3D) and dynamic (4D) volumes were acquired at rest and while the participant performed an MVM. 2D ultrasound videos were then recorded during MVM and maximal voluntary contraction (MVC) efforts of their PFMs. Next, still in standing, participants were instrumented with an intravaginal dynamometer and performed an MVC against arms opened to an antero-posterior diameter of 35 mm. In supine, passive forces were then recorded while the diameter of the dynamometer arms moved from 15 to 40 mm at a constant speed (50 mm/s). The elongation was held for 7 s before the arms returned to their initial position. Three repetitions of each task were performed.

Measures of PFM morphology in 3D included the area of the levator hiatus and its related antero-posterior (AP) and medio-lateral (ML) diameters both at rest and during peak MVM, as well as their change from the start to the peak position during the MVM. Signs of complete and partial levator avulsion were evaluated using the 3D rest volume in standing and the techniques described by Dietz et al. [17, 18]. The measures acquired in 2D included bladder neck (BN) height and levator plate (LP) length and their change from the start to the peak position during each task (MVC and MVM) [19, 20]. These measures have been found to have adequate reliability for use in research [21–23]. Measures of PFM function acquired through dynamometry included baseline force, relative peak force, rate of force development, and static endurance measured as the time from the initial force achieved during the MVC until force decreased by 35% [24, 25]. Passive tissue forces measured during tissue elongation included baseline force, relative peak resistance, rate of force development (stiffness), and the stress relaxation coefficient (SRc). The validity and reliability of these measures and all details of the standardized procedures can be found in previous publications [24, 25].

With a pre-weighed incontinence pad in situ and a Fit-bit Charge 2 worn on the left wrist, the participant began a standardized running protocol on a treadmill (NordicTrack Commercial 2450). Participants increased the belt speed on the treadmill at a self-selected rate to move from walking to a slow jog at a speed of 7 km/h. At this speed, they ran for 2 min, then incremented the belt speed to 10 km/h for 2 min, and finally to 15 km/h for 2 min [26]. The participants were permitted to reduce the belt speed from 15 km/h if they did not feel safe or if they did not have the capacity to run at that speed. The participants were then asked to choose a self-selected speed at an intensity that they deemed to be hard (level 15–16 on the Borg Scale), and to run at that speed for 30 min. After the 30-min steady-state run, the participants ran for 30 s at 10 km/h and then at 7 km/h. Participants were asked to report any instances of perceived leakage of urine while they ran. The ultrasound imaging and intravaginal dynamometry protocols were repeated as

quickly as possible after the running protocol, with data collection completed within 15 min of the end of the run. The pad weight was recorded.

Statistics

Using pilot data from the area of the levator hiatus at rest in standing recorded using transperineal USI before and after a 30-min running protocol from 8 continent runners (mean before 15.99 cm², SD 2.32 cm²; mean after 17.63 cm², SD 2.54 cm²), an a priori two-tailed power calculation using G*Power (version 3.0.10; $\alpha=0.05$; $\beta=0.80$; effect size d_z 0.67) estimated that a minimum of 20 continent runners would be necessary to detect within-group changes induced by the running protocol.

All demographic variables and outcomes were tested for normality using the Shapiro-Wilks test. Mixed-effects ANOVA models were used to compare all outcomes between groups (with or without RI-SUI) and within-groups (before and after the run) including the interaction between group and time. Residual plots were examined to ensure proper model fit, and effect sizes (Cohen's d) were calculated using partial eta squared; $d < 0.2$ were considered small, $0.2 < d < 0.5$ were considered moderate, and $d > 0.5$ were considered large [27]. Based on the observation that not all participants in the group with RI-SUI leaked urine during the protocol, secondary post-hoc exploratory analyses were performed using mixed-effects ANOVAs to evaluate effect sizes between runners with RI-SUI who leaked urine during the protocol vs runners with RI-SUI who did not leak during the protocol, and changes induced by the run within each group. Because of the exploratory nature of this research, the α level ($\alpha=0.05$) was not adjusted to account for multiple comparisons.

Results

Sample demographic information

The recruitment flow diagram is presented in Fig. 1. Twenty participants reported being continent during running, reporting fewer than three lifetime episodes of urine leakage, and 19 runners reported experiencing frequent SUI during running. The groups were similar for most demographic outcomes (Table 1); however, the female runners without RI-SUI were slightly younger ($p=0.01$) and ran slightly faster ($p=0.039$) than the runners who reported RI-SUI, and although there was no difference in parity between the groups, there was a higher proportion of multiparous runners in the RI-SUI group ($p=0.013$). The ICIQ-FLUTS UI subscale score was significantly higher ($p \leq 0.001$) in runners with RI-SUI. The ICIQ-FLUTS scores indicated that 3

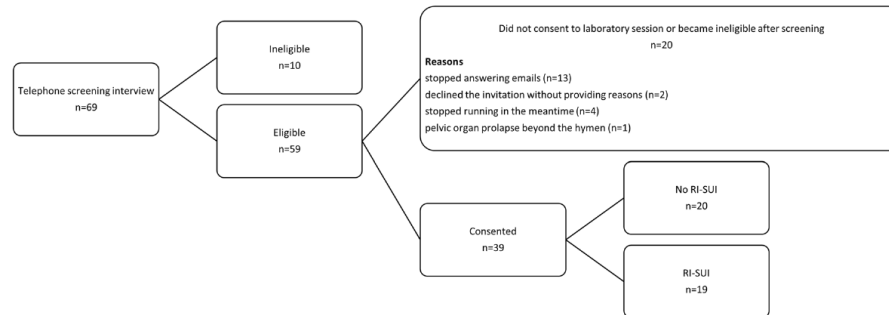


Fig. 1 Flow diagram of the recruitment of the female runners with and without running-induced stress urinary incontinence (RI-SUI)

participants (1 without and 2 with RI-SUI) reported overactive bladder symptoms but none of them reported leakage associated with it during running. Although the runners with RI-SUI had greater pad weight gain after the running protocol than their continent counterparts (8 g versus 30.4 g), this was not statistically different between the groups. Seven out of the 19 runners with RI-SUI did not report being aware of any leakage during the running protocol and had a pad weight gain of less than 8 g over the course of the run. One continent participant had to discontinue the testing protocol after the running protocol as performing the MVM during the USI assessment caused a vasovagal response.

Ultrasound imaging outcomes

The morphological features of the levator hiatus at rest and during MVM are presented in Table 2. Significant and large main effects were found when comparing measures after the run with those measured before the run. At rest, the area ($p=0.002$; $d=1.19$) and AP diameter ($p=0.021$; $d=0.84$) of the levator hiatus were larger after the run for both groups but no change in levator hiatus morphology was observed during peak MVM when performed after the run compared with before the run. At rest, in both groups, the BN height was more caudal within the pelvis ($p<0.001$; $d=2.09$) and the LP was significantly longer ($p<0.001$; $d=1.34$) after the run than before the run. At peak MVC and peak MVM the BN was also more caudal after the run ($p<0.002$; $d=1.20$ and $p<0.001$; $d=1.41$ respectively) compared with before the run in both groups.

The transient changes in morphological outcomes induced by MVC and MVM are presented in Table 3. There was more shortening of the LP during the MVC ($p=0.034$; $d=0.76$) and less lengthening of the LP during the MVM ($p=0.004$; $d=1.08$) after the run compared with before the run in both groups. There was also less caudal displacement of the BN during the MVM in both groups ($p=0.041$; $d=0.73$) after the

run. No significant differences were observed between groups (RI-SUI vs control) and no interactions between group and time (before vs after the run) were observed for any morphological features measured from USI. Missing data (indicated in Tables 2 and 3) were due to poor image/video quality, which prevented the researcher from identifying landmarks (pubis symphysis, anorectal angle, anterior bladder neck) as indicated in the Tables.

Intravaginal dynamometry outcomes

The dynamometry outcomes obtained from the MVC and passive tissue elongation before and after the run are presented in Table 2. No significant between- or within-group differences were found; however, moderate effect sizes were observed for the interaction between group (RI-SUI vs controls) and time (before vs after the run) for strength (relative peak force; $d=0.66$) and power (rate of force development; $d=0.61$) achieved during peak MVC. Although the strength and power achieved during the MVC tended to increase after the run among runners without RI-SUI, relative to their baseline, power tended to decrease, and strength remained unchanged among runners with RI-SUI after the run. During passive tissue elongation, the stiffness and relative peak force tended to be lower in runners with RI-SUI compared with their continent counterparts ($p=0.056$; $d=0.77$ and $p=0.169$; $d=0.54$ respectively), and tended to decrease after the run for both groups ($d=0.47$ and $d=0.47$ respectively). Missing data as reported in Table 2 were due to technical difficulties with the hardware of the intravaginal dynamometer, which prevented the researcher from collecting a complete data set in some cases.

Post-hoc comparison of runners with RI-SUI whose leakage was provoked vs those whose leakage was not provoked during the running protocol

As presented in Table 4, there was a large between-group (those with RI-SUI who leaked vs those with RI-SUI who

Table 1 Demographic information

	No SUI with running (<i>n</i> = 20)		SUI with running (<i>n</i> = 19)		Significance
	Mean/ <i>n</i>	SD/%	Mean/ <i>n</i>	SD/%	
Age (years)	36.2	7.9	43.9	10.6	0.01*
SUI with other activities (<i>n</i> , %)	8	40%	16	84%	$\chi^2(1) = 8.046, p = 0.005^{**}$
BMI (kg/m ²)	22.0	2.3	24.2	5.0	0.184*
Waist to hip ratio	0.8	0.1	0.8	0.1	0.55*
Parous (<i>n</i> , %)	6	30%	11	58%	$\chi^2(1) = 3.083, p = 0.079^{**}$
Primipara (<i>n</i> , %)	3	15%	1	5%	$\chi^2(1) = 1.004, p = 0.316^{**}$
Multipara (<i>n</i> , %)	3	15%	10	53%	$\chi^2(1) = 6.209, p = 0.013^{**}$
Use of forceps (<i>n</i> , %)	1	5%	3	16%	$\chi^2(1) = 1.232, p = 0.267^{**}$
Use of suction (<i>n</i> , %)	0	0%	3	16%	$\chi^2(1) = 3.421, p = 0.064^{**}$
Signs of complete avulsion (<i>n</i> , %)	1	5%	0	0%	$\chi^2(1) = 0.975, p = 0.323^{**}$
Signs of partial avulsion (<i>n</i> , %)	3	15%	4	20%	$\chi^2(1) = 0.242, p = 0.622^{**}$
Menopause (<i>n</i> , %)	1	5%	3	16%	$\chi^2(1) = 1.232, p = 0.267^{**}$
Pelvic floor muscle training (<i>n</i> , %)	2	10%	6	32%	$\chi^2(1) = 2.783, p = 0.095^{**}$
ICIQ-FLUTS total score (/48)	5.0	4.2	9.9	3.3	< 0.001*
ICIQ-FLUTS F (/16)	2.7	2.2	3.3	2.1	0.351*
ICIQ-FLUTS V (/12)	0.7	2.0	0.8	1.3	0.322*
ICIQ-FLUTS I (/20)	1.7	2.0	5.8	2.3	< 0.001*
ICIQ-Bowel total score (1–75)	7.9	6.3	9.3	7.5	0.296*
ICIQ-Bowel pattern (1–21)	3.2	1.4	3.8	1.4	0.235*
ICIQ-Bowel control (/28)	2.2	2.7	2.8	3.3	0.365*
ICIQ-Bowel quality of life (/26)	2.5	4.6	2.7	3.6	0.513*
ICIQ-Vaginal symptoms (/53)	2.7	3.2	4.4	6.0	0.461*
ICIQ-Sexual Matters (/58)	6.9	9.8	3.8	7.9	0.478*
ICIQ-Vaginal quality of life (/10)	0.7	1.3	0.7	1.1	0.923*
IPAQ total activity (MET-min/week)	3,294.7	2,122.5	5,497.0	8,089.7	0.687*
IPAQ subtotal vigorous activities (MET-min/week)	1,278.0	918.2	1,708.9	3,099.0	0.531*
Self-selected running speed (km/h)	10.8	1.2	9.7	1.8	0.039***
Number of steps during running protocol	6,586.8	424.7	6,381.2	305.1	0.095***
Pad test (g) ^a	8.0	5.6	30.4	41.7	0.127*
Weekly running distance (km)	35.2	21.2	39.5	27.7	0.835*
Running experience (years)	15.1	9.2	15.9	12.0	0.792*

Values are presented as mean ± standard deviation (SD) or the frequency and percentage

SUI stress urinary incontinence, BMI body mass index, ICIQ-FLUTS International Consultation on Incontinence—Female Lower Urinary Tract Symptoms Long Form module, IPAQ International Physical Activity Questionnaire, MET metabolic equivalent of task

Significant differences ($\alpha = \leq 0.05$) between groups are indicated in bold

Significance represents the level for between-group differences from the *Mann–Whitney *U* test, **the Chi-squared, or ***the two-sample *t* test

^aOne pad test was over 150 g and our scale had an upper range of 150 g; therefore, it was set to 150 g

did not leak) and time (before vs after the run) interaction effect in terms of the peak position of the BN during the MVC ($p = 0.045$; $d = 0.92$). There was also a large between-group effect for LP length at rest and LP length during peak MVM ($p = 0.013$; $d = 1.40$ and $p = 0.039$; $d = 1.12$ respectively). Indeed, among those with RI-SUI whose leakage was provoked during the running protocol, the BN position sat more caudal within the pelvis, particularly after the

run, and the LP was more elongated. There were also large effect sizes when relative peak force ($p = 0.210$; $d = 0.80$) and stiffness ($p = 0.224$; $d = 0.78$) recorded during passive tissue elongation were compared between the groups—the runners with RI-SUI whose leakage was provoked during the running protocol tended to demonstrate lower resistance of their paravaginal tissues to passive stretch imposed through intravaginal dynamometry.

Table 2 Comparison of intravaginal dynamometry and ultrasound imaging outcomes before and after an acute bout of running between runners with and without running-induced stress urinary incontinence

	Before the run						After the run						Interaction	
	No RI-SUI			RI-SUI			No RI-SUI			RI-SUI				
	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD	p value	Cohen's d
Dynamometry outcomes during MVC														
Baseline (N)	7.90	17	2.68	7.62	12	2.79	7.28	17	2.59	7.27	12	2.16	0.875	0.06
Relative peak force (N)	3.23	17	1.56	4.21	12	1.29	3.73	17	1.89	4.16	12	1.36	0.232	0.47
Rate of force development (N/s)	8.20	17	7.09	11.21	12	3.89	8.86	17	7.88	10.29	12	4.84	0.357	0.36
Endurance (s)	2.23	16	0.55	2.58	12	0.82	2.12	16	1.19	2.33	12	0.70	0.336	0.39
Dynamometry outcomes during passive elongation														
Baseline (N)	1.21	16	0.74	1.55	13	1.39	1.27	16	0.82	1.45	13	1.38	0.527	0.25
Relative peak force (N)	12.73	16	5.60	9.72	13	4.19	12.02	16	7.01	9.48	13	3.38	0.169	0.54
Stiffness (N/s)	34.25	16	10.96	25.50	13	11.09	31.58	16	11.60	25.14	13	8.60	0.056	0.77
Stress relaxation coefficient	-7.20	16	2.26	-7.54	13	2.59	-7.12	16	2.41	-6.87	13	2.30	0.947	0.00
3D ultrasound measurements at rest														
Area (cm ²)	15.65	18	4.29	18.00	17	5.35	16.37	18	4.88	18.84	17	5.16	0.153	0.51
AP diameter (cm)	5.23	18	0.80	5.52	17	0.77	5.36	18	0.86	5.68	17	0.74	0.257	0.40
ML diameter (cm)	3.86	18	0.46	4.23	17	0.73	3.86	18	0.45	4.21	17	0.64	0.068	0.66
3D ultrasound measurements on MVC														
Area (cm ²)	19.52	18	4.97	21.74	18	5.89	19.73	18	4.65	21.94	18	6.16	0.239	0.43
AP diameter (cm)	5.71	18	0.74	6.08	18	0.76	5.75	18	0.76	6.16	18	0.68	0.109	0.59
ML diameter (cm)	4.31	18	0.63	4.57	18	0.78	4.31	18	0.53	4.51	18	0.75	0.327	0.36
2D ultrasound measurements at rest														
BN height (mm)	17.98	19	5.13	16.22	17	3.57	14.66	19	4.54	13.92	17	4.19	0.379	0.31
LP length (mm)	54.88	19	7.48	55.81	18	7.31	57.94	19	9.40	60.01	18	8.10	0.554	0.20
2D ultrasound measurements on MVC														
BN height (mm)	20.83	18	4.88	19.57	17	3.91	18.45	18	5.01	18.65	17	4.27	0.721	0.13
LP length (mm)	45.37	18	8.05	45.52	18	6.23	45.60	18	8.75	45.02	18	5.91	0.929	0.00
2D ultrasound measurements on MVC														
BN height (mm)	8.26	19	6.04	7.32	17	3.83	6.26	19	5.61	5.46	17	4.20	0.594	0.18
LP length (mm)	60.86	17	7.48	60.85	18	9.92	62.96	17	8.60	62.86	18	9.27	0.985	0.00

RI-SUI running-induced stress urinary incontinence, MVC maximal voluntary contraction, MVM maximal Valsalva maneuver, 2D 2-dimensional, 3D 3-dimensional, BN bladder neck, LP levator plate, AP antero-posterior, ML medio-lateral, N/s Newtons per second, SD standard deviation

Significant differences ($\alpha \leq 0.05$) are indicated in bold

Table 3 Assessment of the change in position of the bladder neck and levator plate on ultrasound imaging between runners with and those without running-induced stress urinary incontinence

	Before the run				After the run							
	No RL-SUI		RL-SUI		No RL-SUI		RL-SUI		Between-group		Within-group	
	Mean	n	SD	Mean	n	SD	Mean	n	p value	Cohen's d	p value	Cohen's d
3D ultrasound change on MVM												
Area (cm ²)	3.23	18	2.16	2.92	18	2.20	3.01	18	2.01	0.33	0.127	0.57
AP diameter (cm)	0.46	18	0.62	0.42	18	0.54	0.35	18	0.55	0.14	0.136	0.55
ML diameter (cm)	0.33	18	0.28	0.30	18	0.23	0.32	18	0.23	0.20	0.527	0.23
2D ultrasound change on MVC												
BN height (mm)	2.41	18	2.75	4.36	17	4.10	3.57	18	2.94	0.50	0.143	0.52
LP length (mm)	-9.70	18	4.60	-11.06	18	4.71	-10.84	18	5.65	0.38	0.034	0.76
2D ultrasound change on MVM												
BN height (mm)	-9.71	19	4.00	-8.90	17	4.33	-8.40	19	3.73	0.11	0.041	0.73
LP length (mm)	6.00	17	7.34	5.05	18	5.08	4.63	17	5.33	0.27	0.004	1.08

Negative values indicate a shortening of the levator plate or a caudal descent of BN height

RL-SUI running-induced stress urinary incontinence, *MVC* maximal voluntary contraction, *MVM* maximal Valsalva maneuver, *2D* 2-dimensional, *3D* 3-dimensional, *BN* bladder neck, *LP* levator plate, *AP* antero-posterior, *ML* medio-lateral, *SD* standard deviation

Significant differences ($\alpha = \leq 0.05$) are indicated in bold

Table 4 The effects of running on intravaginal dynamometry and ultrasound imaging outcomes in runners with running-induced stress urinary incontinence, stratified by whether or not leakage was provoked by the running protocol

	Before the run						After the run						Within-group		Interaction			
	Did not leak			Leaked			Did not leak			Leaked			p value	Cohen's d	p value	Cohen's d		
	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD						
Dynamometry outcomes during MVC																		
Relative peak force (N)	4.38	5	1.56	4.08	7	1.19	4.37	5	1.50	4.02	7	1.36	0.689	0.26	0.860	0.11	0.902	0.09
Rate of force development (N/s)	11.66	5	3.18	10.89	7	4.55	11.35	5	4.23	9.53	7	5.42	0.624	0.32	0.254	0.77	0.463	0.48
Dynamometry outcomes during passive elongation																		
Relative peak force (N)	11.49	5	6.04	8.61	8	2.36	11.07	5	4.95	8.48	8	1.62	0.210	0.80	0.587	0.34	0.770	0.18
Stiffness (N/s)	29.48	5	14.37	23.02	8	8.63	29.27	5	11.51	22.56	8	5.58	0.224	0.78	0.884	0.09	0.957	0.00
3D ultrasound measurements at rest																		
Area (cm ²)	17.04	6	6.53	18.53	11	4.85	17.48	6	5.55	19.59	11	5.05	0.513	0.35	0.066	1.02	0.433	0.41
3D ultrasound measurements on MVM																		
Area (cm ²)	21.62	5	7.56	21.80	11	5.40	21.64	5	8.57	22.08	11	5.24	0.926	0.06	0.831	0.11	0.851	0.11
2D ultrasound measurements at rest																		
BN height (mm)	15.80	6	2.27	16.44	11	4.20	14.94	6	3.30	13.37	11	4.66	0.812	0.13	0.006	1.64	0.094	0.92
LP length (mm)	51.18	6	6.88	58.12	12	6.60	53.48	6	5.63	63.28	12	7.21	0.013	1.40	0.026	1.22	0.363	0.47
2D ultrasound measurements on MVC																		
BN height (mm)	18.14	7	3.88	20.58	10	3.79	18.76	7	3.06	18.58	10	5.11	0.572	0.30	0.268	0.59	0.045	1.13
LP length (mm)	42.90	7	6.81	47.19	11	5.51	41.59	7	5.62	47.21	11	5.18	0.085	0.92	0.283	0.56	0.270	0.57
2D ultrasound measurements on MVM																		
BN height (mm)	8.89	6	2.68	6.46	11	4.19	7.71	6	2.48	4.23	11	4.52	0.141	0.80	0.003	1.84	0.290	0.57
LP length (mm)	56.23	6	11.25	63.17	12	8.78	55.55	6	7.42	66.51	12	8.00	0.039	1.12	0.478	0.36	0.288	0.55

MVC: maximal voluntary contraction, MVM: maximal Valsalva maneuver, 2D: 2-dimensional, 3D: 3-dimensional, BN: bladder neck, LP: levator plate, N/s: Newtons per second, SD: standard deviation

MVC maximal voluntary contraction, MVM maximal Valsalva maneuver, 2D 2-dimensional, 3D 3-dimensional, BN bladder neck, LP levator plate, N/s Newtons per second, SD standard deviation

Significant differences ($\alpha = \leq 0.05$) are indicated in bold

Discussion

Both runners with and without RI-SUI experienced significant transient changes, particularly in the morphology of their pelvic floor as measured by USI after they completed a 37-min treadmill running protocol. The changes induced by running appear to predominantly affect the passive support system, as evidenced by the larger area and AP diameter of the levator hiatus, the more caudal position of the BN, and the elongated LP observed in quiet standing after running compared with baseline. Although PFM function, as measured by intravaginal dynamometry, was not significantly affected by the run, the directionality of the observed effects was consistent with the morphological changes. Specifically, the relative peak force and stiffness measured during passive tissue elongation tended to be lower after the run than before the run. And, although differences were not statistically significant, the runners who experienced RI-SUI tended to generate less power after running than before the run, whereas their strength (relative peak force) did not change. Conversely, the runners without RI-SUI tended to generate greater force and more power after the run than before the run. These findings suggest that an acute bout of running might result in strain of the passive tissues within the pelvis, which was observed in all female runners, regardless of whether they experience urine leakage during running. Such changes are likely related to transient changes in the viscoelastic characteristics of the tissues after an episode of repetitive loading—the tissues likely return to their pre-stressed state assuming that there is no underlying damage; however, the cumulative effects of repeated running bouts should be investigated.

Ultrasound imaging

Running caused significant transient morphological changes in pelvic morphology, as measured by 2D and 3D USI, mainly reflecting elongation of the passive supporting structures. Indeed, the passive support structures appeared to be equally affected by the activity in both runners with and those without RI-SUI. Based on these findings, it is plausible that the initial morphological features of the levator hiatus, BN, and LP may serve as a predisposing factor for the development of RI-SUI over the course of a run. It is possible that some threshold exists for the levator hiatus area, LP length, BN height, or a combination of these factors beyond which the passive support to the urethra is no longer sufficient to support and compress it between the anterior vaginal wall and the pubic symphysis to prevent urine leakage. Consistent with this theory, a recent study investigating the likelihood of SUI symptoms being cured by a PFM training intervention found that a resting BN position lower than 14.3 mm in

standing, as measured on 2D USI, was predictive of treatment failure [28]. In the current study, continent runners had a resting BN height that was above this threshold both before and after the run (17.98 mm before vs 14.66 mm after); however, the BN of runners with RI-SUI dropped below this threshold after the run (16.22 mm before vs 13.92 mm after). Although the BN may descend over the course of a run in all female runners, leakage may occur when the BN position ultimately reaches some failure point [28]. This theory is consistent with findings that athletes most often leak urine toward the middle and end of a training session [10].

The significant increase in the extent of shortening of the LP observed during the MVC after the run, and the significant decrease in the extent of lengthening of the LP during the MVM after the run are likely due to a transient increase in the length of the LP. With a longer LP length at rest, the LP had to shorten more during the MVC to achieve the same end-MVC length observed before the run, and similarly the LP did not have as much room to lengthen during MVM before it reached its ultimate endpoint. As with the LP, the significant reduction in both groups in the extent of BN descent observed during the MVM after the run can be attributed to the lower resting position of the BN after the run, which was already close to its maximal descent.

Intravaginal dynamometry

Although not significant, the trends observed on dynamometry are worth discussing, as the effect sizes were moderate to large; yet these results should be interpreted with caution. Runners with RI-SUI demonstrated a 9% reduction in the contractile power of their levator ani muscles after running, whereas their strength remained unchanged. In contrast, the runners without RI-SUI tended to have greater strength (14% increase) and power (8% increase) after the run than before the run. These results align somewhat with previous findings among nulliparous females with mild SUI, where a mean reduction in maximal vaginal closure pressure induced by MVC of the levator ani muscles was substantive (-20%) but not significant following a 90-min exercise session that included 20 min of running [29]. Also, in line with the current findings, there were changes neither in vaginal resting pressure nor in the time over which an MVC could be sustained (i.e., static endurance) following the exercise session [29]. The current results are also consistent with findings that, following a 20-min as many repetitions as possible (AMRAP) workout, strenuous exercisers (27.7% with symptoms of urine leakage) demonstrated significantly more vaginal descent and significantly lower vaginal resting pressure [30], without concurrent changes in maximal vaginal closure pressure during MVC after the exercise [30]. A control group of nonstrenuous exercisers (8.57% with symptoms of urine leakage) completed a 20-min walk, and no

differences were observed between the strenuous exercisers and the control group in terms of effect on pelvic organ support and vaginal closure pressure despite the different intensity of the exercise [30]. Both the current study and these previous results reinforce the idea that an acute bout of exercise may have a greater impact on passive pelvic organ support rather than PFM contractile function.

Although not significant, stiffness and peak passive force measured through dynamometry tended to be compromised in the runners with RI-SUI relative to their continent counterparts, which align with the observed morphological changes in all runners. Although both groups demonstrated similar reductions in stiffness and peak passive forces after completing the running protocol, the group with RI-SUI had lower absolute stiffness and lower peak passive forces after the running protocol. Further, the runners with RI-SUI whose leakage was provoked during the running protocol appeared to experience greater strain than those with RI-SUI whose leakage was not provoked. More research with a larger sample size is needed to establish the contribution of the loss of passive tissue stiffness in RI-SUI.

Limitations

This study focused on experienced female runners and thus the findings may not be generalizable to infrequent runners. The sample included middle-aged nulliparous and parous, mostly white, healthy females. Although the outcomes of this investigation might be transferable to other athletes who engage in running as a component of other physical activities, the results may not be applicable to all athletes. Whereas the runners without RI-SUI selected a faster treadmill speed than their incontinent counterparts (10.8 km/h versus 9.7 km/h), step counts during the running protocol were not different between the groups, suggesting that, even though loading may have been higher in the continent group, the pelvic tissues were exposed to a similar number of loading cycles in both groups with comparable levels of exertion (15–16 on the Borg Scale). Indeed, had the runners with RI-SUI run at the same intensity as their continent counterparts, the observed changes may have been greater.

Vaginal birth is a known risk factor for SUI, and it impacts the morphology and functioning of the PFMs. Although efforts were made to balance parity as a dichotomous variable between the recruited groups, there was a higher proportion of female runners with multiple childbirths in the RI-SUI category in contrast to those without. Nonetheless, an equal number of participants in both groups ($n=4$) exhibited levator avulsion (partial or complete). Additional alterations in the pelvic floor linked to parity such as nerve damage might have played a role in affecting the findings of this investigation.

Neural, metabolic, and vascular components of the continence system could impact differences in the force generation capacity of the PFMs after the run; however, these were not assessed in the present study. Indeed, although PFM surface electromyography (EMG) was pilot tested as an outcome to be measured concurrently with intravaginal dynamometry in this study, it was deemed not to be feasible, as the arms of the dynamometer caused significant motion artifact in the EMG signals, intravaginal electrodes were dislodged by the dynamometer arms, and adhesive electrodes lifted, particularly after the run, owing to perspiration, urine, and/or vaginal secretions.

Not all runners with RI-SUI leaked urine during the protocol. A longer or more strenuous protocol may have induced greater changes in morphology and function than was observed here. Although the sample size was small, this hypothesis is supported by the exploratory post-hoc analysis presented in Table 4. Among the runners with RI-SUI, those whose leakage was provoked during the running protocol, findings point to greater reductions in pelvic organ support compared with those with RI-SUI who did not experience leakage during the protocol. Although participants were evaluated quickly after the running protocol (within 15 min), it is possible that the passive PFM tissue properties may have recovered somewhat by the time the passive tissue elongation was performed. As such, the extent of tissue strain induced by the running protocol may be larger than that reported here.

A final limitation of this study is the extent of missing data that resulted from hardware failure in the intravaginal dynamometer and poor image quality during USI, which resulted in a smaller sample size for some outcomes. The interpretation of the results is also subject to the limitations of the instruments themselves. For instance, although intravaginal dynamometry is considered a gold standard for the measurement of PFM active and passive tissue properties, it remains a coarse measurement as it is influenced by all closure forces acting on the dynamometer arms [31, 32]. USI measurements can be influenced by changes in the angle of the transducer during acquisition and the incorrect identification of landmarks [31].

That said, the innovative approach used in this study to investigate the effects of an acute bout of running on active and passive pelvic floor support structures contributes to our understanding of RI-SUI. The findings point to practical approaches that focus on enhancing pelvic floor support such as PFM training and the use of pessaries to effectively mitigate or prevent symptoms of athletic incontinence in females. If pelvic floor support is enhanced prior to an acute bout of running, it might prevent the pelvic structures from descending below a critical threshold that leads to the failure of the continence system over the course of a run.

Conclusion

The findings of this study indicate that a 37-min bout of treadmill running causes transient strain in the passive tissues in the pelvic floor, leading to significant loss of pelvic organ support among runners with and without RI-SUI. The findings revealed no evidence to support the hypothesis that the running protocol induced contractile fatigue in the PFM. Future research should be aimed at investigating the time course of morphological changes that occur during running, as well as recovery profiles.

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Data Availability All data relevant to the study are included in the article. Should any raw data files be needed in another format they are available from the corresponding author upon reasonable request.

Declarations

Conflicts of interest The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article.

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Appendix S: Original article included in Chapter 5

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ORIGINAL ARTICLE



The Feasibility of Using an Intravaginal Intra-Abdominal Pressure Sensor During Running to Evaluate Pelvic Floor Loading and Its Association with Running-Induced Stress Urinary Incontinence: An Observational Cohort Study

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Abstract

Introduction and Hypothesis The aim was to investigate the feasibility of using an intravaginal intra-abdominal pressure (IAP) sensor worn by female runners during running to evaluate pelvic floor loading, and the association between IAP and running-induced stress urinary incontinence (RI-SUI).

Methods Twenty-eight female runners participated in this cross-sectional study (15 with RI-SUI and 13 continent). Participants completed a 37-min treadmill running protocol instrumented with an intravaginal sensor measuring IAP, and a skin-mounted accelerometer measuring pelvic accelerations. Linear regression analyses evaluated the relationship between IAP and pelvic acceleration. One-way ANOVAs assessed the impact of running speed on IAP. Sensor dislodgement was recorded, and effect sizes (Cohen's *d*) were calculated for the comparison of IAP and accelerometry outcomes between runners with and without RI-SUI.

Results Intra-abdominal pressure showed high variance and the sensor was expelled in almost 15% of participants. Positive associations were found between pelvic acceleration and both absolute peak and normalized IAP but explained only between 12% and 18.6% of the variance in the models. Pelvic acceleration during running was not associated with cumulative IAP. Peak IAP significantly increased with running speed. Although IAP tended to be higher in runners with RI-SUI than in continent runners (Cohen's *d* between 0.14 and 0.74), pelvic accelerations tended to be lower (Cohen's *d* between 0.02 and 0.55).

Conclusions There is high variance in IAP recorded during running using an intravaginal sensor. Faster speeds increase pelvic floor loading. Runners with RI-SUI may experience higher IAP than continent runners, warranting investigation. Recruitment should include a 15% data loss rate owing to sensor expulsion.

Keywords Biomechanics · Intra-abdominal pressure · Pelvic floor · Running · Urinary incontinence

Abbreviations

AUC Area under the curve
IAP Intra-abdominal pressure

PFM Pelvic floor muscle
RI-SUI Running-induced stress urinary incontinence
SUI Stress urinary incontinence

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Introduction

Pelvic floor loading is thought to be a key factor in the development of stress urinary incontinence (SUI) symptoms during exercise [1]. This hypothesis is primarily based on the observation that symptoms of urine leakage are highly prevalent during high-impact activities, particularly among female runners [2–5]. However, there are scant existing data on this topic, and findings are inconsistent [1]. Runners report that urine leakage tends to occur

after some period of running without leakage, suggesting a cumulative effect of pelvic floor loading [6]. Indeed, acute running bouts seem to adversely affect pelvic organ support in runners, evidenced by a larger levator hiatus, a longer levator plate, and a lower bladder neck observed after running among runners both with and without running-induced (RI)-SUI when compared with measurements taken prior to the run [7]. Peaks or cumulative pelvic floor loading during repetitive high-impact activity may increase the risk of experiencing RI-SUI, but this has not been evaluated empirically.

Intra-abdominal pressure (IAP) is considered an important factor in pelvic floor loading. When performing dynamic tasks including sit-to-stand, walking, lifting, fall recovery, and jumping, the magnitude of pressure measured by an IAP sensor located within the posterior fornix appears to be influenced by hip acceleration, respiration volume, and flexion moment of the trunk and abdominal wall [8], which, combined, appear to account for 60% of the peak IAP. During upright activities, pressure measurements at the posterior fornix likely reflect a combination of IAP and gravitational loading on the pelvic floor. Studies have reported high variability in peak IAP measured during physical tasks when a sensor is located in the posterior fornix [9–11]. Some have reported an increase in IAP during the transition from walking to running [12, 13] and increases in IAP with increased walking speed and inclination [13, 14]. A strong positive correlation ($r=0.7220$) was found between IAP and pelvic acceleration measured during walking, and the authors concluded that pelvic accelerometry might be a valid way to estimate pelvic floor loading, yet this association may not be causal, and it has not been validated during running [14].

Given that females limit the intensity of their physical activity because of lower urinary tract symptoms [15], there is an urgent need to understand the pathomechanics at play to guide the development of biomechanical interventions to mitigate urine leakage. Measuring pelvic floor loading during running using an IAP sensor placed within the posterior fornix may help us to fill this knowledge gap. Yet first we must determine the feasibility of this approach, through understanding how to interpret IAP outcomes when measured during running. A first step is to understand the contribution of running parameters (speed, pelvic acceleration) to peak and cumulative IAP measured in this way, and the stability of the sensor across the running task.

The aim of this exploratory study was therefore to determine the feasibility of using an intravaginal IAP sensor worn while running to investigate differences in pelvic floor loading between female runners with and those without RI-SUI. The objectives were:

1. To determine the relationship between vector (Euclidean norm) and vertical pelvic accelerations observed during

running and pelvic floor loading measured through an intravaginal IAP sensor.

2. To evaluate the impact of running speed on pelvic floor loading measured through the intravaginal IAP sensor.
3. To evaluate the stability of intravaginal IAP sensor measurements made during running at two fixed speeds before and after a 30-min treadmill running protocol.
4. To observe the rate of sensor dislodgement throughout the protocol.
5. To estimate the effect sizes associated with differences in IAP and acceleration measures of pelvic floor loading during running.

The outcomes of this research contribute to the development of robust measures to elucidate the pathomechanics associated with RI-SUI among females.

Materials and Methods

Design

This observational, cross-sectional study received approval from the local institutional research ethics board prior to recruitment. Recruitment and data collection were completed between June 2019 to March 2021, with a pause between March 2020 and January 2021 owing to laboratory closures caused by the COVID-19 pandemic. All participants provided written informed consent prior to completing any aspect of the protocol.

Participants

Experienced runners assigned female at birth, over 18 years of age, and with no known risk factors related to physical activity were recruited from the local community through local running groups and physiotherapy clinics. Volunteers were required to meet the following exposure criteria: run at least 5 km in under 50 min twice a week, having sustained an average running distance of > 10 km per week for a minimum of 1 year. During the telephone screening interview, runners were classified as continent if they self-reported never having experienced urine leakage during running and not leaking urine during activities of daily living. Conversely, runners with RI-SUI were required to self-report leakage at least 2 to 5 times per month while using mitigation strategies (voiding their bladder before/during the run, running at a slower pace, avoiding hills, etc.) and to leak more than once per week when not using these strategies. Participants who experienced occasional instances of urinary urgency during running without any associated leakage were included; however, they were excluded if they experienced leakage related to urgency during running. Additional

exclusion criteria were: a history of urogenital surgery or neurological disorders, self-reported symptoms of energy deficiency as measured by the Low Energy Availability in Females Questionnaire (LEAF-Q) [16], pregnancy or in the first post-partum year, pelvic organ prolapse caudal to the hymen on a maximal Valsalva maneuver (MVM) performed in a standing position, or pelvic pain experienced to the extent that they were not able to insert a vaginal tampon. After providing written informed consent, all eligible participants provided demographic information, including age, parity, obstetrical history (i.e., vaginal versus Caesarean section, use of forceps), their leakage profile during running, and menopausal status. They were then asked to complete the International Consultation on Incontinence—Female Lower Urinary Tract Symptoms (ICIQ-FLUTS) Long Form module and the International Physical Activity Questionnaire (IPAQ) [17].

Laboratory Assessment

Participants with a menstrual cycle were asked to attend during the follicular phase of their menstrual cycle, determined as the 1st week following the cessation of menstrual bleeding. The laboratory assessment was performed by a registered physiotherapist trained in the assessment and treatment of pelvic health conditions, and who had over 5 years of experience in this practice area prior to data collection. She was trained to use the IAP sensor. The participants inserted a validated [18–20], reliable [12], sterilized, and calibrated (0 to 350 cm H₂) IAP sensor into the posterior fornix of their vagina. Adequate positioning of the device was confirmed by the physiotherapist using digital palpation. The participants were then instructed to don their underwear and a pair of running shorts to hold all the wires in place. IAP sensor data were acquired at a sampling frequency of 40 Hz and stored on an SD card within an instrumented module that was secured to the left iliac crest with adhesive tape. To ensure that the intravaginal sensor was securely located in the upper third of the vagina, the participants were instructed to stand up and perform three maximal effort coughs and three maximal Valsalva maneuvers (MVMs). To ensure comparability of IAP measurements between subjects, the IAP data recorded during running were normalized to those recorded during vertical jumping. The participants were asked to perform three vertical jumps from the ground, as this task is less effort dependent than coughing or Valsalva. The instruction given was: “When I signal you, jump as high as you can, as if you are trying to touch the ceiling.” During the tasks, if the sensor descended below the levator hiatus, it was reinserted, and the process was repeated. If the sensor still descended, the participant was removed from the study.

An accelerometer (MetaMotion®; Mbientlab Inc.) with a range of ± 16 gravitational units (g) was adhered directly to

the skin over the upper border of the left mid-iliac crest and was used to record raw acceleration values in the vertical, anteroposterior, and mediolateral directions at a sampling frequency of 100 Hz.

Participants moved to the treadmill (NordicTrack Commercial 2450) and began by walking, increasing the belt speed to 7 km/h. They jogged for 2 min, then increased the speed to 10 km/h and ran for 2 min, then increased the speed to 15 km/h and ran for 2 min. The participants could discontinue running at 15 km/h if they did not feel safe or if they did not have the capacity to sustain this speed. In these cases, they ran at their fastest comfortable pace for the remainder of the 2-min period. The participants were then asked to choose a speed to run at for 30 min, at an intensity that they deemed to be hard (levels 15–16 on the Borg Scale). After 30 min of running, the participants ran for 30 s at 10 km/h then at 7 km/h. IAP data were logged into the instrumentation module throughout the protocol whereas samples of pelvic acceleration were taken in bursts of 15-s duration during each running condition. If a participant felt short of breath or discomfort during the running task, they could slow their speed for 1 min before resuming the same running speed. Participants were not restricted from drinking water during the running protocol. After the protocol, the researcher removed the accelerometer and inspected the IAP sensor to record whether it was still located within the posterior fornix of the vagina before removing it.

Outcomes

All raw IAP data were inspected for noise interference through visual inspection of the time series and power spectra. No filtering was deemed necessary. The mean IAP jump value was calculated for the vertical jump normalization task as the average of three trials using the net IAP value (maximal value during the jump and minimal value before the jump) [21]. For IAP data collected during the running protocol, IAP peaks were identified using a custom MATLAB program. Peaks were required to be at least 0.2 s apart to reduce sampling bias (Fig. 1). The highest and lowest IAP values obtained from each of the different running speeds (7 km/h at the start and end of the protocol, 10 km/h at the start and end of the protocol, 15 km/h at the start of protocol, self-selected speed) were used to compute the net mean peak IAP at each speed and time point where applicable [22]. The net mean peak IAP was normalized to become the relative net mean peak IAP obtained across each running speed, calculated as a percentage of the mean IAP recorded during vertical jumping (IAP jump).

To consider cumulative effects, the IAP time series were integrated by calculating the area under the curve (AUC) over 10 s at each running speed and time where applicable

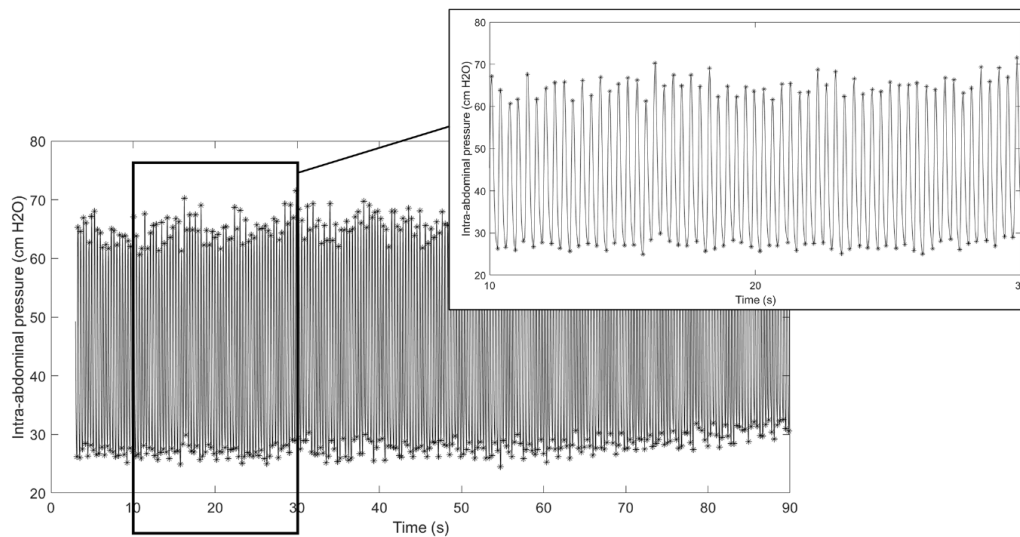


Fig. 1 Raw intra-abdominal pressure data (centimeters of water (cm H₂O)) versus running time (s) at a speed of 7 km/h. The asterisks represent all the maxima and the minima that were used to estimate the

average net mean peak intra-abdominal pressure (average of the local maxima minus average of the local minima). The zoomed-in panel shows a detailed view of intra-abdominal pressure over a 20-s interval

[22] (i.e., 7 km/h [start/end], 10 km/h [start/end], 15 km/h [start], and over 10 min for the self-selected speed).

Using a separate custom MATLAB program, raw pelvic acceleration data were filtered using a second-order, dual-pass Butterworth filter with a 6-Hz cut-off. The vertical acceleration (a_y) and the vector acceleration (Euclidean norm) $|\vec{a}|$ (Eq. 1, where a_x , a_y , and a_z represent acceleration values in the x (antero-posterior), y (vertical), and z (medio-lateral) planes respectively were averaged over ten consecutive steps for each running speed using the peak acceleration values from each step.

$$|\vec{a}| = \sqrt{a_x^2 + a_y^2 + a_z^2}. \quad (1)$$

Statistical Analysis

Statistical models were generated using IBM SPSS version 28, and $\alpha=0.05$ was used for all tests. The IAP and acceleration outcomes were tested for normality using the Shapiro–Wilk test.

For the demographic outcomes, parametric (t test) or nonparametric (Mann–Whitney U) analyses were applied as appropriate to assess group differences between runners with and those without RI-SUI, whereas Chi-squared tests were used to analyze group differences in dichotomous variables. Descriptive statistics of the IAP and acceleration

measurements were calculated for each running speed separately for runners with and those without RI-SUI. The standard deviation and the average range between the three trials of the IAP during the jump tasks were calculated. Regression analyses with pooled data from all participants were conducted to evaluate the relationship between pelvic accelerations (a_y and $|\vec{a}|$) and IAP outcomes (net mean peak IAP, relative net mean peak IAP normalized to vertical jumping, and IAP AUC with data from all running speeds pooled). A one-way ANOVA was used to test differences in net mean peak IAP, relative net mean peak IAP, and AUC IAP among running speeds (7 km/h, 10 km/h, 15 km/h). To evaluate the stability in the IAP outcomes across the running protocol, paired sampled t tests were carried out to compare the net mean peak IAP and normalized net mean peak IAP before and after the 30-min run at both 10 and 7 km/h speeds. IAP jump, IAP outcomes, and accelerations during running were compared in runners with and in those without RI-SUI using parametric (t test) or nonparametric (Mann–Whitney U) tests as appropriate. The coefficients of variation were calculated as well as Cohen's d effect sizes, where $0.2 \leq d < 0.5$ were considered small, $0.5 \leq d < 0.8$ were considered moderate, and $d \geq 0.8$ were considered large [23]. The effect sizes were then used to calculate the requisite sample size for a future study, ensuring sufficient statistical power (two-tailed power calculation using G*Power version 3.0.10;

$\alpha=0.05$; $\beta=0.80$), to detect differences between runners with and those without RI-SUI.

Results

Sample Demographic Information

Sixty-nine female runners underwent screening, 39 of whom were eligible to participate and successfully completed the laboratory assessment. Technical difficulties were encountered with the instrumentation module or the SD card of the IAP sensor in 5 participants, and the sensor was dislodged from the vagina during the running task in 6 participants. Ultimately, IAP data were collected from 28 participants. Sample demographic data are presented in Table 1. Runners with RI-SUI reported significantly higher scores on the Incontinence subscale of the ICIQ-FLUTS. Otherwise, both groups were similar across all other demographic outcomes. The average standard deviation among the three trials of the jump was 7.64 cm H₂O and the average range was 14.32 cm H₂O (70.96–85.28 cm H₂O). There was moderate variance in the IAP data, as demonstrated by the coefficient of variation, which ranged from 0.18 to 0.35 for the net mean peak IAP, from 0.19 to 0.39 for the relative net mean peak IAP, and from 0.17 to 0.22 for the AUC IAP (Table 2).

Relationship between IAP and Pelvic Acceleration

Figure 2 illustrates the moderate positive associations between net mean peak IAP and vector ($r=0.347$; $R^2=0.1202$; $p\leq 0.001$; panel A) and vertical ($r=0.432$; $R^2=0.1864$; $p\leq 0.001$; panel D) acceleration. There were moderate positive associations between relative net mean peak IAP normalized to vertical jumping and vector ($r=0.346$, $R^2=0.120$, $p<0.001$; panel B) and vertical ($r=0.421$, $R^2=0.177$, $p<0.001$; panel E) acceleration. There were no significant associations between IAP AUC and vector ($r=0.063$; $R^2=0.004$; $p=0.538$; panel C) or vertical ($r=0.159$; $R^2=0.025$; $p=0.120$; panel F) acceleration.

Impact of Running Speed on IAP

The net mean peak IAP and the AUC IAP at 7, 10, and 15 km/h are presented in Fig. 3. There was a significant increase in net mean peak IAP with increased running speed ($p=0.01$); net mean peak IAP was higher at 15 km/h than at 7 km/h ($p=0.009$). There were no differences in IAP between the 7- and 10-km/h or between the 10- and 15-km/h speeds. Although the same trend was observed for the relative net mean peak IAP and the AUC IAP, it was not significant.

Table 1 Demographic data for the experienced female runners

	Participants ($n=28$)		No SUI with running ($n=13$)		SUI with running ($n=15$)	
	Mean or n	SD or %	Mean or n	SD or %	Mean or n	SD or %
Age (years)	40.63	10.74	36.86	9.20	43.90	11.56
BMI (kg/m ²)	23.25	3.54	22.32	2.52	24.05	4.26
Waist to hip ratio	0.79	0.08	0.78	0.10	0.80	0.05
Parous	11	39	4.00	31%	7.00	47%
Use of forceps, n , (%)	3	11	1.00	8%	2.00	13%
Use of suction, n , (%)	1	4	0.00	0	1.00	7%
Menopause, n (%)	4	14	1.00	8%	3.00	20%
ICIQ-FLUTS total score, /48	7.82	4.53	4.62	3.75	10.60	3.33*
ICIQ-FLUTS F, /16	3.21	2.06	2.54	2.11	3.80	1.97
ICIQ-FLUTS V, /12	0.68	1.1	0.31	0.48	1.00	1.41
ICIQ-FLUTS I, /20	3.93	3.13	1.77	2.35	5.80	2.60*
IPAQ total activity, MET-min/week	5,454.04	6,505.5	4,028.96	2,230.06	6,689.10	8,766.99
IPAQ subtotal vigorous activities, MET-min/week	1,813.93	2,521	1,520.00	1,016.40	2,068.67	3,416.93
Self-selected running speed, km/h	10.15	1.68	10.66	1.21	9.71	1.99
Number of steps during running protocol	6,388.7	310.26	6,449.00	363.68	6,340.47	275.90
Weekly running distance (km)	35.21	22.6	33.85	17.78	36.40	27.33
Running experience (years)	15.76	10.85	16.23	9.58	15.35	12.50

RI-SUI/running-induced stress urinary incontinence, BMI/body mass index, ICIQ-FLUTS/International Consultation on Incontinence—Female Lower Urinary Tract Symptoms, F filling domain, V voiding domain, I incontinence domain, IPAQ/International Physical Activity Questionnaire, MET/metabolic equivalent of task

*Significant differences ($\alpha<0.05$) between groups

Table 2 Intra-abdominal pressure and accelerations outcomes between runners with and those without running-induced stress urinary incontinence (RI-SUI)

	No RI-SUI					RI-SUI					Cohen's <i>d</i>
	Mean	SD	Range	CoV	<i>n</i>	Mean	SD	Range	CoV	<i>n</i>	
IAP jump (cm H ₂ O)											
Vertical jump	85.21	21.88	59.28–138.48	0.26	13	74.52	17.45	44.39–105.84	0.23	15	0.54
Net mean peak IAP (cm H ₂ O)											
7 km/h	41.28	7.52	30.63–55.10	0.18	13	42.66	11.99	18.40–60.62	0.28	15	0.14
10 km/h	43.20	8.27	33.71–62.53	0.19	13	45.57	12.12	22.94–68.67	0.27	15	0.23
15 km/h	48.56	11.10	33.51–76.07	0.23	12	54.19	14.44	34.22–79.45	0.27	12	0.44
SSS	41.58	8.85	25.07–58.20	0.21	12	45.64	15.96	17.06–77.42	0.35	15	0.31
Relative net mean peak (% IAP vertical jump)											
7 km/h	51.32	15.07	24.70–75.70	0.29	13	59.84	21.64	34.3–98.70	0.36	15	0.45
10 km/h	53.85	16.55	26.60–78.30	0.31	13	63.73	20.90	41.00–100.40	0.33	15	0.52
15 km/h	60.89	20.59	29.40–96.60	0.34	12	72.88	23.78	44.90–109.50	0.33	12	0.54
SSS	50.42	16.45	27.80–76.80	0.33	12	63.57	24.57	32.20–99.80	0.39	15	0.62
AUC over 10 s (cm H ₂ O·s)											
7 km/h	176.34	30.51	133.54–224.46	0.17	13	189.95	36.79	109.34–245.77	0.19	15	0.40
10 km/h	176.22	28.27	129.68–216.69	0.16	13	195.09	32.42	139.75–239.15	0.17	15	0.62
15 km/h	188.83	42.23	129.25–292.06	0.22	12	218.09	36.29	140.37–266.30	0.17	12	0.74
AUC over 10 min (cm H ₂ O·s)											
SSS	10,080.52	2,077.41	6,901.93–14,267.44	0.21	12	11,061.96	2,326.04	6,881.47–15,339.76	0.21	15	0.44
Vector acceleration (g)											
7 km/h	3.28	0.44	2.72–3.93	0.14	12	3.18	0.40	2.58–4.01	0.13	14	0.24
10 km/h	3.58	0.52	2.73–4.25	0.14	10	3.38	0.34	2.78–3.89	0.10	14	0.46
15 km/h	3.63	0.41	2.92–4.12	0.11	10	3.64	0.50	2.76–4.38	0.14	11	0.02
SSS	3.59	0.41	2.82–4.24	0.11	13	3.44	0.41	2.75–4.23	0.12	15	0.37
Vertical acceleration (g)											
7 km/h	2.36	0.24	2.05–2.78	0.10	12	2.32	0.26	1.83–2.70	0.11	14	0.16
10 km/h	2.59	0.27	2.09–3.09	0.11	10	2.49	0.26	2.15–2.92	0.10	14	0.38
15 km/h	2.77	0.24	2.21–2.95	0.09	10	2.69	0.29	2.27–3.21	0.11	11	0.30
SSS	2.65	0.24	2.18–3.10	0.09	13	2.50	0.30	2.06–3.26	0.12	15	0.55

RI-SUI running-induced stress urinary incontinence, IAP intra-abdominal pressure, cm H₂O centimeters of water, cm H₂O·s centimeters of water times seconds, AUC area under the curve, *n* sample size, SSS self-selected speed, SD standard deviation, *g* gravitational acceleration, CoV coefficient of variation

Consistency in IAP Measurements

No significant difference was found between the net mean peak IAP recorded during running at 10 km/h before and after the 30-min run (mean before $\pm$ SD = 44.63 $\pm$ 10.89 cm H₂O; mean after $\pm$ SD = 43.89 $\pm$ 12.00 cm H₂O; p = 0.663). However, the net mean peak IAP was significantly lower after the 30-min run than before the run when participants ran at 7 km/h (mean before $\pm$ SD = 41.41 $\pm$ 10.51 cm H₂O; mean after $\pm$ SD = 37.93 cm H₂O $\pm$ 11.53; p = 0.038). Similar results were observed for relative net mean peak IAP normalized to vertical jumping.

Sensor Dislodgement

The sensor was dislodged in 3 participants with RI-SUI and in 3 continent runners, among which 5 were parous and 1 was nulliparous.

Intra-Abdominal Pressure and Accelerations Between Runners with and without Running-Induced Stress Urinary Incontinence

Table 2 presents the IAP and acceleration outcomes observed across all running speeds for runners with and

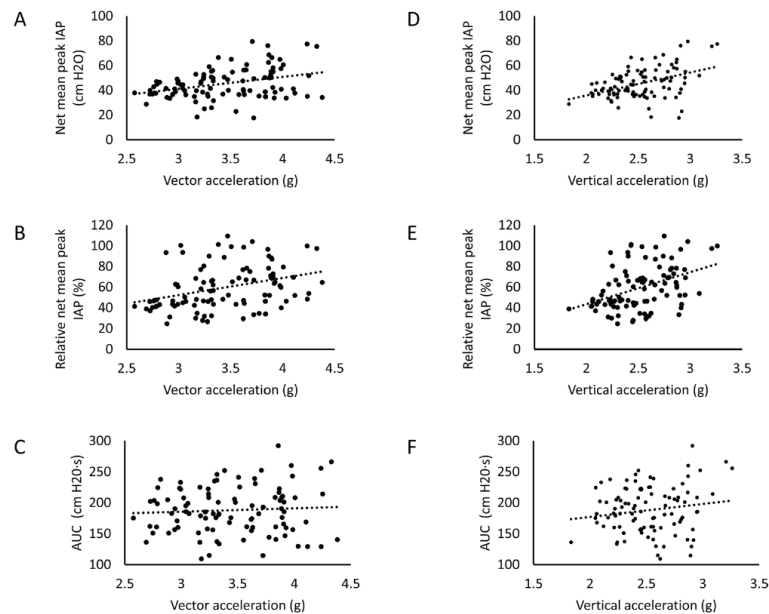


Fig. 2 The relationship between vector acceleration and the vertical acceleration (gravitational unit=g) with net mean peak intra-abdominal pressure (IAP) in centimeters of water (cm H₂O), with relative net mean peak IAP normalized to vertical jumping and the area under the curve (AUC) in centimeters of water times seconds (cm H₂O-s). There were significant regressions between net mean peak IAP and vector (panel A: $r=0.347$; $R^2=0.120$; $p<0.001$) and vertical (panel

D: $r=0.432$; $R^2=0.186$; $p=0.001$) acceleration and between relative net mean peak IAP during vertical jumping and vector (panel B: $r=0.346$, $R^2=0.120$, $p<0.001$) and vertical (panel E: $r=0.421$, $R^2=0.177$, $p<0.001$) acceleration. The linear regressions between the AUC IAP with the vector (panel C: $r=0.063$; $R^2=0.004$; $p=0.538$) and vertical (panel F: $r=0.159$; $R^2=0.025$; $p=0.120$) acceleration were not significant

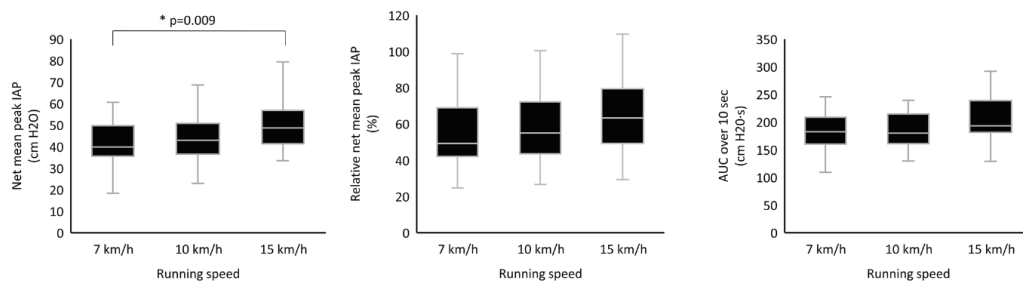


Fig. 3 Intra-abdominal pressure (IAP) outcomes (net mean peak IAP, relative net mean peak IAP normalized to vertical jump and integrated IAP) observed during treadmill running at 7, 10, and 15 km/h.

Asterisk indicates a significant difference between running speeds. cm H₂O centimeters of water, cm H₂O-s centimeters of water times seconds, AUC area under the curve

those without RI-SUI. No significant differences were found between the groups for any of the outcomes. There was a wide range of the net mean peak IAP, relative net mean peak IAP, and AUC measured at all speeds. The coefficients of

variation (COV) for the IAP outcomes were moderate for net mean peak IAP (ranging from 0.18 to 0.35) and did not improve when normalized to the vertical jump (ranging from 0.29 to 0.39). The AUC IAP resulted in the least amount of

variation ($0.16 < \text{COV} < 0.22$). As for the vector and vertical acceleration, the COVs were small, ranging from 0.09 to 0.14.

Moderate effect sizes suggest that participants with RI-SUI might experience higher net mean peak IAP, relative net mean peak IAP, and AUC IAP than continent runners, especially at fast (15 km/h) running speeds ($d=0.44$ for net mean peak IAP, $d=0.62$ for relative net mean peak IAP, and $d=0.74$ for AUC IAP). Overall, runners with RI-SUI tended to experience lower accelerations than continent runners ($0.24 \leq d \leq 0.55$), except for vector acceleration at 15 km/h, which was similar in the groups ($d=0.02$).

Not accounting for data loss through instrumentation issues ($n=5$) among early participants, which were resolved, considering that the sensor became dislodged from the vagina in 6 out of the 39 participants (approximately 15%), power calculations using the computed effect sizes suggest that a total sample size of 66 participants (33 in each group of runners) would be needed to detect between-group differences in runners with and in those without RI-SUI for cumulative loading (AUC IAP $d=0.44$) and 260 runners to detect differences in peak loading (net mean peak IAP $d=0.31$) at the self-selected speed.

Discussion

The results from this study show that, although feasible, measures made using an intravaginal IAP sensor located in the posterior fornix of the vagina have high variance when used to measure pelvic floor loading during running. This high variance is consistent with IAP measurements taken among exercising women reported by other groups that used the same sensor [9–11], but also with other sensors such as a wireless gastric sensor [24] and an intrarectal sensor [25], during a variety of exercises/tasks. Despite high variance in IAP, positive correlations have been reported between total vector pelvic accelerations and peak IAP during walking ($r=0.7220$) [14], leading to a recommendation that waist-worn accelerometers are a valid method for inferring IAP during a variety of activities [14]. In the current study, when women ran at speeds ranging from 7 to 15 km/h, the relationship between pelvic acceleration and peak IAP was much weaker ($r=0.347$ for $|\vec{a}|$, $r=0.432$ for a_y) and does not support the use of pelvic acceleration to infer peak IAP during running. Running requires more respiratory effort, trunk rotation, and abdominal muscle activation than walking. These variables are known to contribute to IAP [8], which might explain the weaker relationship found between peak IAP and pelvic accelerations during running in this study than during walking in other studies. The lack of a significant relationship between IAP AUC and pelvic acceleration

during running is consistent with previous findings during walking tasks [14] and suggests that pelvic accelerations should not be used to infer cumulative loading forces experienced by the pelvic floor during running, particularly considering that we observed moderate effect sizes pointing to runners with RI-SUI experiencing higher IAP but lower pelvic accelerations during running.

Intra-abdominal pressure measured using a pressure sensor located in the posterior fornix has been validated [18–20] and found to be reliable during physical activities [12] but not specifically during running tasks, where the sensor may be more prone to descent or expulsion. Although the sensor did dislodge in 6 participants, it appeared to remain in position in the others, and IAP was stable during the period before and during that after the steady-state run when the belt speed was 10 km/h. This finding can be considered confirmation that sensor migration was not a problem. It is unclear why IAP was lower after the run when the belt speed was 7 km/h. It is unlikely that the sensor migrated between the 10 km/h and 7 km/h conditions after the run, as these phases were only 30 s in duration and the runners had already been running for 36 min by this point. The lower IAP measured after the run at the 7-km/h speed might be associated with the viscoelastic properties of the pelvic floor tissues. Previous work suggested that an accelerometer embedded in the IAP sensor might not have descended over the course of the treadmill protocol but that pelvic floor accelerations during running might have been dependent on belt speed and parity [26]. As such, changes in the properties of the pelvic floor connective tissues may have been induced by the prolonged run but were only detectable at the 7-km/h running speed. We did observe that several participants altered their running mechanics once the belt speed was slowed to 7 km/h at the end of the run, which may have influenced IAP, but we did not record running mechanics in any quantifiable way.

We found no previous studies that examined the effect of different normalization tasks to normalize IAP data acquired during active tasks. The vertical jump task appears to be a good choice for normalization. Although the normalization of the IAP resulted in larger effect sizes between runners with and those without RI-SUI than non-normalized IAP (net mean peak), it also increased the variance in the IAP data. Further research is needed to determine the most appropriate method for normalizing IAP data during different activities. In the case of running, it appears prudent to evaluate both non-normalized IAP and to normalize peak IAP by vertical jumping to fully explore the contributions of IAP and gravitational loading to the sensor output. Other tasks could also be considered for normalization.

Faster running speeds tended to increase the net mean peak IAP, relative net mean peak IAP, and AUC IAP; however, this effect was only significant for net mean peak IAP,

and post hoc testing revealed that there was a difference in the net mean peak IAP only between the 7-km/h and the 15-km/h running speeds, tasks in which there is a substantial difference in locomotive effort. These results are consistent with previous work that found net mean peak IAP increased with locomotive effort when a small group of mostly nulliparous women walked at 1.7 miles per hour at a 10% grade, at 2.5 miles per hour at a 12% grade, and at 3.4 miles per hour at a 14% grade [14]. Although the findings of the current study could lead to recommendations that runners limit their running speed to minimize IAP and consequently the risk of experiencing or developing SUI symptoms, this advice is not supported—both because of the observed high intra-individual variance in IAP and the current lack of empirical evidence that IAP exposure during running causes SUI. Indeed, although some runners experienced low IAP at high running speeds, others experienced as much as twice the IAP at that same speed.

The intravaginal IAP sensor was dislodged during running in 6 participants (3 with and 3 without RI-SUI), reducing the effective sample size from 34 (after instrumentation failure in 5) to 28. Five out of the 6 participants in whom the sensor dislodged were parous. Changes in pelvic floor morphology induced by vaginal birth were likely the primary reason for this. Other studies using this sensor during Pilates exercises [9] and during a range of physical tasks [12] reported similar rates of sensor dislodgement. These results suggest that design modifications might be necessary to improve the retention rate of the sensor in parous women, particularly over an extended run. Adjustments to the sensor's size, its shape, or even the texture of the silicone, could enhance the fit and reduce the risk of dislodgement. Regarding the technical difficulties encountered with the sensor, the repetitive vibrations caused by running led to connector failure in several early participants. Fortunately, this issue was resolved through reinforcement of the connectors as the study proceeded. Future studies using this intravaginal IAP sensor should plan their sample size with a 15% attrition rate related to sensor loss, especially if investigating parous women over an extended run.

Based on the effect sizes computed here, peak loading (net mean peak IAP), IAP normalized to a vertical jump, and cumulative loading (IAP AUC) during an acute bout of running appear to be good candidate measurements for studying biomechanical factors contributing to RI-SUI, particularly investigating running speed. A next step is to evaluate the relationship between pelvic floor loading and changes in pelvic floor muscle (PFM) morphology and function observed over the course of a running session. Because the effect sizes are moderate at best, factors other than the magnitude of the loading stress imposed on the pelvic floor during the running task likely contribute

to RI-SUI and should also be considered. Factors beyond running biomechanics may also influence urethral or PFM structure, support, and/or function [7], such as the timing and amount of activation of the PFMs observed in runners during foot strike and toe off [27, 28].

Although this sensor may be considered less invasive than sensors located in the rectum or stomach [20], there are inherent limitations to its use. Indeed, the pressure outcomes recorded by the sensor during running reflect both IAP and compressive forces generated between the viscera and the pelvic floor. Although this can be seen as a limitation, the resulting pressure outcomes likely reflect overall pelvic floor loading, which is the construct of interest in understanding the pathophysiology of RI-SUI.

Although running is a component of numerous physical activities and sports, it is important to note that the findings from this study cannot be applied to other high-impact activities. Also, the running protocol was completed in a controlled environment on a treadmill and may not reflect how the participants would habitually run. The results from this study are generalizable only to experienced runners who are mainly premenopausal and have low BMI. Running technique, heart rate, respiration pattern, running kinematics and kinetics, and abdominal muscle activation are all factors that could influence IAP experienced during running [8]; however, these were not assessed in the present study. Although the sample size was small, it allowed us to estimate the future sample size needed to achieve adequate statistical power and to troubleshoot some concerns related to using an vaginal IAP sensor over an extended run.

Conclusion

This study explored the feasibility of using an intravaginal IAP sensor in female runners to measure pelvic floor loading during an extended treadmill run. Although there were positive associations between running speed and IAP, IAP had high variance. Similarly, the associations between pelvic acceleration and IAP were moderate. Although the IAP was not different before and after the 30-min run, when the belt speed was 10 km/h, IAP was lower after the run, when the belt speed was 7 km/h, possibly reflecting viscoelastic changes in the pelvic floor tissues or changes in running mechanics during the cool-down. Future research should anticipate a minimum attrition rate of 15% due to sensor dislodgement. The evidence is currently lacking to support biomechanical interventions for RI-SUI and future studies should be aimed at investigating the impact of pelvic floor loading during exercise on changes in PFM morphology and function.

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Authors' Contributions M.E. Berube: project development, data collection, data processing, data analysis, manuscript writing, revision process; S. Niederauer: project development, data processing, revision process; R. Graham: project development, data processing, revision process; R. Hitchcock: project development, revision process; L. McLean: project oversight, project development, project infrastructure and funding, data analysis, manuscript writing, revision process.

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Data Availability Data may be requested from the corresponding author.

Declarations

Ethics of Approval Statement The study protocol was approved by the Research Ethics Board of the University of Ottawa.

Conflicts of Interest The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article.

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Appendix T: Original article included in Chapter 6

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Original Article



Is pelvic floor loading in female runners associated with post-run changes in pelvic floor morphometry or function?

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Objectives

To investigate whether, among female runners, transient changes in pelvic floor morphometry, pelvic floor muscle (PFM) function, or pad weight gain observed after a standardised running protocol are associated with the exposure of the pelvic floor to loading during the run.

Methods

Adult female runners with ($n = 19$) and without ($n = 19$) running-induced stress urinary incontinence (RI-SUI) completed a 37-min treadmill-based running protocol with a pressure sensor placed in the posterior fornix of the vagina and a triaxial accelerometer adhered to the pelvis, and an incontinence pad adhered to their undergarment. Pelvic morphometry and PFM function were assessed before and after the run using transperineal ultrasonography and intra-vaginal dynamometry. Urine leakage volume was estimated based on incontinence pad weight gain. Separate linear regression models were used to evaluate the associations between variables representative of pelvic floor load exposure (posterior fornix sensor pressure [PFSP] and pelvic accelerations) and changes in pelvic morphometry, PFM function, and incontinence pad weight observed after the run.

Results

After the run, the levator hiatus was larger and the bladder neck sat lower in the pelvis, but there were no significant differences in PFM active or passive forces measured using dynamometry. These changes were not different between those with and those without RI-SUI. Higher pelvic accelerations were associated with greater reductions in passive PFM stiffness after the run ($R^2 = 20\%–27\%$), but not with changes in pelvic morphometry. No associations were found between any measures of pelvic floor load exposure and changes in PFM force-generating capacity. Among runners with RI-SUI, greater pad weight gain occurred among those who ran with slower vector accelerations ($R^2 = 0.27$).

Conclusion

The magnitude of pelvic floor loading experienced during running does not appear to influence the transient loss in static pelvic organ support observed after running nor urine leakage volume.

Keywords

intra-abdominal pressure, pelvic floor, posterior fornix sensor pressure, running, urinary incontinence, accelerations, biomechanics

Introduction

Running is a popular activity and a component of many sports. However, a significant number of female runners report discontinuing this form of exercise due to prevalent lower urinary tract symptoms [1], mainly stress urinary incontinence (SUI) [2–5]. Exposure to high-impact forces during activities such as running has been proposed as a

contributor to incontinence experienced during athletic activities [6,7]. High intra-abdominal pressure (IAP) has also been hypothesised to lead to symptoms of SUI during athletic activities [8–15].

Few studies on exercise-induced SUI have focused on runners. A recent study found that a 37-min run induced a loss of passive support without concurrent pelvic floor muscle

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(PFM) fatigue [14]. Another study found that after performing a half-marathon, female runners experienced fatigue-related changes in PFM function including strength, endurance, and ability to complete repeated contractions [16]. de Melo *et al.* [15] investigated biomechanical correlates of urinary incontinence among runners, finding no differences in running mechanics between runners with and without urinary incontinence. They also found no association between the severity of leakage experienced during running and these running mechanic parameters [15]. Similar results were found in a sample of postpartum runners where, during a 7-min treadmill run, there was no evidence of an association between symptoms of pelvic floor dysfunction and both running kinetics and pelvic accelerations [17].

Pressure measured by a sensor positioned within the posterior fornix of the vagina has been theorised to reflect pelvic floor loading [18–22]. Such sensors have been used to infer pelvic floor loading in groups of females performing different physical activities [18–22]. Pressure sensor data have, however, been highly variable among individuals who perform different exercise activities. The sensor measures higher pressure with tasks that increase IAP (abdominal wall muscle contraction, higher respiration volume and greater trunk flexion) and those associated with inertial loading (higher pelvic acceleration) [23], but it remains unclear how exposure of the pelvic floor to these forces affects pelvic organ support or PFM function. The magnitude of accelerations experienced by the pelvis during running likely reflects the magnitude of mechanical stresses experienced by the PFMs and connective tissues related to inertial loads and ground reaction forces being transmitted up the kinetic chain [18]. Such mechanical stress may lead to tissue strain, and, consequently, a loss of pelvic organ support. Currently, it is not clear how exposure to loading during running ultimately contributes to urine leakage among females. Understanding these relationships will allow us to explore biomechanical interventions to prevent or alleviate symptoms of SUI experienced by females during physical activities such as running.

The aim of this study was to determine, among experienced female runners, if the magnitude of loading experienced by the pelvic floor tissues (inferred both through pressure recorded by a sensor placed in the posterior fornix and through pelvic accelerations) over the duration of a standardised treadmill running protocol is associated with the extent of observed changes in pelvic floor morphometry or PFM function observed after the run. A second aim was to assess if the extent of urine leakage measured among runners with running-induced stress urinary incontinence (RI-SUI) is associated with the magnitude of pelvic floor loading experienced during running. Our primary hypothesis was that greater pelvic floor loading would be associated with greater reductions in pelvic organ support and PFM stiffness

measured after the run. Our secondary hypothesis was that, among female runners with RI-SUI, higher pelvic floor loading would be associated with more urine leakage during the run.

Methods

Study Design

This was an observational, cross-sectional exploratory study. Our local institutional research ethics board approved the protocol prior to recruitment, which occurred between June 2019 and March 2021, with a break between March 2020 and January 2021 due to laboratory closures caused by the COVID-19 pandemic. Prior to participating in any part of the protocol, all participants provided written informed consent.

Participants

Experienced runners were recruited through local running groups and physiotherapy clinics. The inclusion and exclusion criteria are presented in Table 1. All eligible participants provided demographic information including age, parity, obstetric history (i.e. vaginal vs Caesarean section, use of forceps or suction) and menopausal status. Participants were also asked to complete the International Consultation on Incontinence-Female Lower Urinary Tract Symptoms Long Form module (ICIQ-FLUTS) and the International Physical Activity Questionnaire (IPAQ) [24], and to provide general information about their running profile such as frequency, volume, and experience. Due to the novel nature of this study, there were no prior data available to inform a sample size estimate. Consequently, the sample size was determined based on practical considerations and the availability of resources, with assumptions that a sample size >25 would be adequate to detect moderate linear associations [25].

Laboratory Assessment

The first author, a registered physiotherapist who has worked exclusively in pelvic health, and with over 5 years of experience at the time of data collection, conducted all laboratory assessment data. Additionally, she received over 50 h of training on ultrasonography and intra-vaginal dynamometry to assess pelvic morphometry and PFM function prior to initiating this study and was trained on and deemed competent by the device developers on the correct use of the pressure sensor.

Further details on the procedures used in this study can be found in a previous publication [14]. In brief, using transabdominal ultrasonography, bladder volume was confirmed to be between 100 and 200 mL to ensure consistency among participants during the running protocol.

Table 1 Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
- Runners assigned female at birth - Older than 18 years old - Run at least 10 km/week for the past year - Run at least twice per week for the past year - Can run at least 5 km in under 50 min	- Risk factors for physical activity according to Par-Q - Self-reported obesity or obesity defined by a BMI > 35 kg/m² - History of urogenital surgery and/or use of incontinence medication - Neurological impairments involving the central nervous system or the sacral nerves - Known connective tissue disorders - Pelvic organ prolapse that moves caudally past the hymen on Valsalva manoeuvre while standing - Pregnant or had delivered a baby within the previous year - Dyspareunia or pelvic pain - Symptoms of low energy deficiency as measured by the Low Energy Availability in Females Questionnaire (LEAF-Q) <i>In situ</i> devices that would not be suitable for ultrasonography, intra-vaginal dynamometry, and/or intra-vaginal pressure sensor placement - Urinary urgency with associated urine leakage during running

BMI, body mass index.

This decision was made to assess urine leakage during exercise with a moderately full bladder since female runners tend to void their bladder prior to going for a run and even during the run as a mitigation strategy to prevent leakage [26]. Before running, the morphometry of the PFM was assessed using two-dimensional (2D) and three-dimensional (3D) B-mode transperineal ultrasonography through a GE Voluson S6 system (General Electric, Toronto, ON, Canada). While in a standardised standing position, static 3D volumes (to measure the area of the levator hiatus [LH]) and dynamic 2D clips (to measure levator plate [LP] length and bladder neck [BN] height) were obtained at rest and during maximum effort voluntary contractions (MVCs). Also, in standing position, an intravaginal dynamometer was used to measure MVC forces. The arms were opened to an anteroposterior diameter of 35 mm and the participant was instructed to perform an MVC. The participant then moved to a supine position and the dynamometer was used to record passive forces as the diameter of the dynamometer arms moved at a constant 50 mm/s from 15 to 40 mm diameter. The elongation was held for 7 s before the arms returned to their initial position. Three sequential repetitions of each task were performed using each device.

The dependent variables were selected as those previously shown to be impacted by an acute bout of running among experienced female runners both with and without RI-SUI [14]. Imaging outcomes included the area of the LH at rest, acquired using 3D imaging in standing position, and BN

height and LP length at rest, acquired using 2D imaging in standing position. The amount of change (Δ) in the LP length and BN height was acquired as the difference in these measures between rest and peak MVC [27,28]. Dynamometry outcomes included peak force and rate of force development observed during active contraction in standing position and passive PFM elongation in supine position [29,30]. The relevance of each outcome is presented in Box 1.

The participants proceeded to insert a validated [31–33], reliable [34], sterilised, and calibrated (0–350 cm H₂O) pressure sensor into the posterior fornix of their vagina, which was zeroed to atmospheric pressure. Adequate positioning of the device was confirmed by the physiotherapist using digital palpation in the supine position by palpating the cervix and ensuring that the sensor was inserted posterior to it and as far as possible. The participants were then instructed to get dressed again in their underwear and in standardised Spandex running pants provided by the laboratory, which held the wires still while running. Posterior fornix sensor pressure (PFSP) data were acquired at a sampling rate of 40 Hz and stored on a Secure Digital card within an instrumented module that was secured to the participant's left iliac crest with adhesive tape. To ensure that the sensor was securely positioned in the upper third of the vagina, the participants were instructed to stand up and perform three maximal effort coughs, three maximal Valsalva manoeuvres, three vertical jumps, and three repetitions of a standardised lifting task with 6.8 kg in each hand. On visual inspection, if the sensor descended into the lower part of the vagina or came out, it was reinserted, and the process was repeated. If the sensor still descended, it was removed, and the participant continued the study without the sensor. A tri-axial accelerometer (MetaMotionR; Mbitlab Inc.) with a range of $\pm 16g$ was adhered using tape directly to the skin over the upper border of the left mid-iliac crest and was used to record pelvis acceleration values in the vertical, anteroposterior and mediolateral directions at a sampling rate of 100 Hz.

With a pre-weighed incontinence pad in their underwear, and a fitness tracker watch (Fitbit) on their wrist, participants proceeded to a NordicTrack Commercial 2450 treadmill. They gradually increased the belt speed to 7 km/h, jogged for 2 min, then increased the speed to 10 km/h, ran for 2 min, then increased the speed to 15 km/h, ran for 2 min then selected a running speed that they perceived as somewhat hard (15–16 on the Borg Rate of Perceived Exertion Scale) and maintained it for 30 min, after which they decreased the treadmill speed to 10 km/h and then 7 km/h, running for 30 s at each speed, at which point they reduced the speed to zero to end the protocol. Throughout the entire protocol, the instrumentation module recorded pressure data. If the participants experienced shortness of breath or discomfort during the running task, they had the option to reduce their

speed or, if necessary, walk for 1 min before resuming their selected speed. Drinking water during the running protocol was permitted. Following completion of the running protocol, the physiotherapist examined the positioning of the pressure sensor, determining whether or not it remained within the posterior fornix of the vagina before removing it. The ultrasonography and intra-vaginal dynamometry procedures were then repeated as described above, completed within 15 min of the end of the running protocol. Pad weight and total number of steps taken during the run were recorded. The researcher who conducted the laboratory assessment was not blinded to continence status as she could visually detect urine in the pad on removal for weighing.

Data Processing

The change in PFM outcomes was calculated as the difference between the post-run measurements and the pre-run measurements.

All PFSP data processing was performed using custom MATLAB programs and followed methods previously established by the developers of the device [35]. Following a power spectrum analysis, no filtering was deemed necessary to smooth the pressure data as there was no evidence of high frequency noise. Maxima and minima in the pressure data were identified using custom software, with successive peaks being at least 0.2 s apart. Confirmation via visual inspection ensured that pressure peaks were identified correctly. Four separate measures were derived from the PFSP data to quantify pelvic floor load exposure. Firstly, the difference between the mean of all maxima and of all minima was used to compute the 'net mean peak PFSP' during the 30-min run at the self-selected speed [35]. Secondly, the net mean peak PFSP calculated over the highest data point acquired during the three vertical jumps [36] was used to normalise the net mean peak PFSP during running, producing the third measure, the 'relative net mean peak PFSP'. This measure, presented as a percentage, was used to allow meaningful comparisons among individuals considering variations in body mass and the mass of the abdominal/pelvic organs. Fourthly, the area under the PFSP curve (PFSP AUC) was averaged over 10 min of running at the self-selected speed to represent cumulative loading [35]. While these measures were not independent (net mean PFSP vs relative net mean PFSP $r = 0.777$; net mean PFSP vs PFSP AUC $r = 0.879$, relative net mean PFSP $r = 0.635$), they were each selected as they provide different information about pelvic floor loading.

The raw pelvic acceleration time series were smoothed using a second order dual-pass Butterworth filter with a 6-Hz cut-off. Vector accelerations (vertical [y], sagittal [x] and coronal [z]) were computed over 10 consecutive steps at the self-selected speed within the 15-min mark of the 30-min run, using the peak acceleration values from each step

(Equation 1), where a_x (sagittal), a_y (vertical), and a_z (coronal), represent acceleration amplitudes in the x , y , z directions, respectively, and $|\vec{a}|$ represents the vector acceleration. Again, while not independent ($r = 0.693$), both vector and vertical accelerations provide different information and were thus both included in the statistical analyses.

$$|\vec{a}| = \sqrt{a_x^2 + a_y^2 + a_z^2} \quad (1)$$

Statistical Analysis

All statistical testing was carried out using IBM SPSS version 28 and $\alpha = 0.05$ was used for all tests. All outcomes were tested for normality using the Shapiro-Wilks test. Descriptive statistics (mean, SD) were calculated for each outcome. Confidence intervals were calculated for the mean difference in PFM outcomes to describe the acute effects of the run. To test the primary hypothesis, separate linear regression analyses were conducted to evaluate the relationships between pelvic floor loading variables (net mean PFSP, relative net mean PFSP, PFSP AUC, vector acceleration and vertical acceleration) recorded during the run and changes in pelvic morphometry and PFM function after the run. The baseline value of each PFM morphometry or function outcome was included in its respective models as a covariate, since it was previously shown that baseline values of BN height and LP length can affect the extent of changes observed after a run [14]. To assess our secondary objective, among female runners with RI-SUI, linear regression analyses were conducted to evaluate the relationship between each of the variables representing pelvic floor loading and pad weight gain after the running protocol. Residual plots were examined to ensure proper model fit.

Results

Sample Demographic Information

Thirty-nine female runners met the eligibility criteria. However, only 38 successfully completed the laboratory-based assessment due to hardware issues with the dynamometer. Hardware difficulties due to faulty connections were encountered with the vaginal pressure sensor for another five participants. PFPS data were discarded for six participants due to the sensor having descended from the posterior fornix during the running task. Ultimately, PFSP datasets were available from 27 participants.

Demographic data are presented in Table 2. Baseline values, post-run values and mean differences in all PFM outcomes are summarised in Table 3. The LH was significantly larger, and the BN was significantly lower within the pelvis in standing position at rest after the run. Runners were also able

Table 2 Demographic data for the whole sample ($n = 38$) and for participants in whom posterior fornix sensor pressure data were available for regression analysis ($n = 27$).

	All participants ($n = 38$)		PFPS subset ($n = 27$)	
	Mean/ n	SD or %	Mean/ n	SD or %
Age, years	39.91	10.12	40.74	11.13
BMI (kg/m^2)	23.03	3.99	23.25	3.68
Waist to hip ratio	0.79	0.07	0.79	0.08
Parous	17	45	11	41
Use of forceps ($n, \%$)	4	11	3	11
Use of suction ($n, \%$)	3	8	1	4
Menopause ($n, \%$)	4	11	4	15
Rt-SUI ($n, \%$)	19	50	15	56
ICIQ-FLUTS total score (/48)	7.37	4.56	8.07	4.50
ICIQ-FLUTS F (/16)	2.89	2.13	3.33	2.04
ICIQ-FLUTS V (/12)	0.79	1.70	0.67	1.14
ICIQ-FLUTS I (/20)	3.68	3.02	4.07	3.15
IPAQ total activity (MET-min/week)	4389	5951	5531	6739
IPAQ subtotal vigorous activities (MET-min/week)	1503	2268	1819	2616
Self-selected running speed (km/h)	10.30	1.64	10.16	1.77
Number of steps during running protocol	6489	384	6408	307
Weekly running distance (km)	36.2	23.6	36.1	23.0
Running experience (years)	15.70	10.54	15.49	11.17

Values are presented as mean $\pm$ SD or frequency and percentage (%). BMI, body mass index; F, filling subscore; I, Incontinence subscore, IPAQ, International Physical Activity Questionnaire; ICIQ-FLUTS, International Consultation on Incontinence-Female Lower Urinary Tract Symptoms Long Form module; MET, metabolic equivalent units; PFSP, posterior fornix sensor pressure; Rt-SUI, running-induced stress urinary incontinence; V, voiding subscore.

to shorten their LP further when performing an MVC after the run. The PFSP and pelvic acceleration data measured during the 30-min self-selected running speed are detailed in Table 4. The equations derived from the regression analyses

are presented in Table S1. While most models were nonsignificant, as described below, the residual plots confirmed that all models met the necessary criteria for adequate model fit.

Relationship Between Changes in Pelvic Floor Loading Exposure During Running and Changes in Pelvic Morphometry and PFM Function After the Run

The outcomes of the linear regression analyses are presented in Table 5. The only regression models that were significant were the amount of change in relative peak passive force observed on PFM elongation and pelvic accelerations (both vertical and vector) observed during running. Figures 1 and 2 present scatterplots showing the relationships between pelvic floor loading exposure (net mean PFSP and pelvic vertical accelerations) and both dynamometry and ultrasonography outcomes, respectively. The outcome of the regression analyses is described in more detail below.

Dynamometry Outcomes

Contractile forces There was no difference in MVC force or rate of force development after the run compared to before the run. The extent of pelvic loading (PFSP, pelvic accelerations) exposure during running did not affect the magnitude or rate of force generated during PFM MVC. The regression models suggest that pelvic floor loading during the run explains little to none of the variance (1%–12%) in the change in contractile force observed after the run (Fig. 1).

Passive tissue elongation As noted above, exposure to higher pelvic accelerations, both vertical and vector, was associated with reduced rate of force development during passive

Table 3 Baseline outcomes and post-run changes measured by intra-vaginal dynamometry and ultrasonography.

	Before the run		After the run		Difference (Δ)			n
	Mean	SD	Mean	SD	Mean	SD	95% CI	
Dynamometry outcomes during MVC								
Rate of force development (N/s)	9.45	6.08	9.45	6.72	0.00	2.70	−1.024 to 1.033	28
Relative peak force (N)	3.64	1.51	3.91	1.68	0.27	0.86	−0.054 to 0.602	28
Dynamometry outcomes during passive elongation								
Rate of force development (N/s)	30.33	11.69	28.69	10.70	−1.64	6.58	−4.137 to 0.865	28
Relative peak force (N)	11.38	5.16	10.88	5.73	−0.50	2.05	−1.280 to 0.279	28
3D ultrasonography measurements								
LH area at rest (cm^2)	16.90	4.94	17.70	5.12	0.80	1.35	0.324 to 1.267	33
2D ultrasonography measurements at rest								
BN height (mm)	16.75	4.78	14.59	4.13	−2.16	3.29	−3.273 to −1.049	35
LP length (mm)	55.59	8.24	56.92	9.06	1.33	4.55	−0.187 to 2.848	36
2D ultrasonography measurements change on MVC								
BN height (mm)	3.36	3.56	4.01	2.94	0.66	2.55	−0.218 to 1.532	34
LP length (mm)	−10.38	4.64	−11.89	5.59	−1.51	4.07	−2.890 to 0.133	35

Confidence intervals significantly different from zero are shown in bold. Δ , absolute difference; 2D, two-dimensional; 3D, three-dimensional; BN, bladder neck; LH, levator hiatus; LP, levator plate; MVC, maximal voluntary contraction; N/s, Newtons per second; N, Newtons.

Table 4 Pelvic floor loading outcomes measured using intra-vaginal posterior fornix sensor and pelvic accelerometers during running for 30-min at a self-selected speed.

	<i>n</i>	Mean	sd	Range	CoV (%)
Net mean peak PFSP (cm H ₂ O)	27	43.84	13.21	17.66–77.42	30.1
Relative net mean peak PFSP (%)	27	57.72	22.00	27.80–99.80	38.1
AUC PFSP (cm H ₂ O.s)	27	177.10	37.22	114.69–255.66	21.0
Vertical acceleration (g)	38	2.62	0.28	2.06–3.26	10.2
Vector acceleration (g)	38	3.52	0.40	2.75–4.24	11.7

AUC, area under the curve; CoV, coefficient of variation; g, gravitational unit; PFSP, posterior fornix sensor pressure.

elongation of the PFMs after the run (i.e. stiffness) and with peak passive resistance (Fig. 1) after the run, with models explaining between 20% and 27% of the variance in the data. Pelvic floor loading exposure, when measured through PFSP (net mean PFSP, relative net mean peak PFSP, and AUC PFSP) was not associated with changes in pelvic floor tissue stiffness measured using vaginal dynamometry after the run, with models explaining between 5% and 20% of the variance (Fig. 1).

Ultrasonography Outcomes

Levator hiatus While LH area was larger when measured in standing position at rest after the run, the magnitude of pelvic floor loading exposure (measured through both PFSP and pelvic accelerations) was not associated with the extent of observed changes after the run. The models explained

between 8% and 12% of the variance in PFSP and between 1% and 4% of the variance in pelvic accelerations (Fig. 2).

Bladder neck height The BN height was lower when measured in standing position at rest after the run compared to before the run. Pelvic accelerations explained between 28% and 30% of the variance in the change in BN height at rest after the run (Fig. 2). During the MVC, there was more elevation of the BN after the run. For the PFSP variables, the regression models explained between 21% and 49% of the variance in the data, however, the significant predictor in these models was BN height before the run, not the loading exposure during the run. Runners who initially had a more cranial BN position before the run were more likely to experience greater caudal shifts in BN position afterward, both at rest and on MVC.

Levator plate length The LP was not significantly longer after the run. Neither pelvic accelerations nor PFSP had a meaningful impact on the resting length of the LP, nor its ability to shorten on MVC after the run compared to baseline. The regression models explained between 3% and 16% of the variance in the data (Fig. 2).

Relationship between Pelvic Floor Loading and Pad Weight Gain among Runners with RI-SUI

Among the runners with RI-SUI, PFSP (net mean PFSP, relative net mean PFSP, AUC PFSP) explained little to no variance in pad weight gain ($n = 15$, $R^2 = 0.039$ [95% CI $-1.415, 0.703$], slope = -0.356 , $P = 0.481$; $R^2 = 0.000$ [95% CI $-0.726, 0.677$], slope = -0.025 , $P = 0.941$; $R^2 = 0.048$ [95% CI $-0.597, 0.271$], slope = -0.163 , $P = 0.432$,

Table 5 Regression coefficients and CIs for the relationships between pelvic floor loading (posterior fornix sensor pressure and pelvic accelerations) and change in pelvic floor muscle function and morphometry outcomes.

	Net mean PFSP			Relative net mean PFSP			AUC PFSP			Vertical acceleration			Vector acceleration		
	R^2	<i>B</i>	95% CI	R^2	<i>B</i>	95% CI	R^2	<i>B</i>	95% CI	R^2	<i>B</i>	95% CI	R^2	<i>B</i>	95% CI
Dynamometry outcomes during MVC															
Rate of force development	0.01	0.026	-0.128 to 0.180	0.02	0.016	-0.067 to 0.099	0.008	0.002	-0.045 to 0.050	0.00	0.071	-4.083 to 4.225	0.081	1.985	-0.72 to 4.690
Relative peak force	0.10	-0.019	-0.064 to 0.026	0.07	0.005	-0.018 to 0.029	0.118	-0.007	-0.021 to 0.007	0.01	-0.028	-1.348 to 1.292	0.094	0.683	-0.205 to 1.571
Dynamometry outcomes during passive elongation															
Rate of force development	0.17	-0.104	-0.498 to 0.291	0.19	-0.077	-0.268 to 0.115	0.175	0.035	-0.083 to 0.154	0.26	-7.141	-15.913 to 1.631	0.27	-5.187	-11.181 to 0.807
Relative peak force	0.20	-0.098	-0.217 to 0.020	0.18	-0.046	-0.107 to 0.015	0.048	0.004	-0.036 to 0.045	0.20	-3.399	-6.228 to -0.569	0.273	-2.747	-4.585 to -0.908
3D ultrasonography measurements															
LH area at rest	0.12	-0.022	-0.066 to 0.022	0.12	-0.014	-0.042 to 0.013	0.082	-0.003	-0.019 to 0.013	0.01	-0.347	-2.233 to 1.538	0.037	-0.635	-1.825 to 0.555
2D ultrasonography measurements at rest															
BN height	0.21	0.046	-0.035 to 0.128	0.48	0.020	-0.027 to 0.067	0.491	0.016	-0.014 to 0.045	0.30	-1.455	-5.151 to 2.241	0.281	-0.130	-2.750 to 2.490
LV length	0.03	0.096	-0.076 to 0.267	0.11	0.054	-0.043 to 0.151	0.088	0.026	-0.034 to 0.087	0.08	4.538	-1.105 to 10.181	0.012	-0.804	-4.749 to 3.141
2D ultrasonography measurements change on MVC															
BN height	0.35	0.000	-0.082 to 0.082	0.35	-0.003	-0.050 to 0.043	0.35	-0.001	-0.03 to 0.028	0.34	0.867	-1.873 to 3.607	0.352	0.841	-1.054 to 2.736
LP length	0.16	-0.095	-0.253 to 0.063	0.16	-0.055	-0.143 to 0.033	0.132	-0.025	-0.08 to 0.031	0.06	-2.377	-7.889 to 3.136	0.058	1.797	-2.089 to 5.684

2D, two-dimensional; 3D, three-dimensional; AUC, area under the curve; *B*, beta coefficient of the regression for the PFSP or pelvic accelerations; BN, bladder neck; LH, levator hiatus; LP, levator plate; MVC, maximal voluntary contraction; PFSP, posterior fornix sensor pressure; R^2 , coefficient of determination.

respectively). While similar results were obtained for vertical accelerations ($R^2 = 0.015$ [95% CI $-92.952, 56.604$], slope = -18.174 , $P = 0.615$), slower vector accelerations were associated with greater pad weight gain after the run ($R^2 = 0.273$ [95% CI $-100.193, -9.053$], slope = -54.623 , $P = 0.022$; $n = 19$).

Sensor Dislodgement

Five out of the six participants in whom the sensor dislodged were parous. We compared pelvic floor morphometry and dynamometry between the parous runners in whom the sensor became dislodged and those in whom the sensor remained within the posterior fornix (Table S2). There were no significant between-group differences but the LH and LP of the parous runners who lost the sensor tended to be larger and longer, there was less tissue stiffness during passive elongation of the paravaginal tissues and PFM force-generating capacity was lower.

Discussion

To our knowledge, this is the first study to explore the direct relationship between pelvic floor loading during a single exercise session and transient changes in pelvic floor morphometry and function observed afterward. The results provide some evidence that pelvic floor loading, particularly when inferred through pelvic accelerations, may contribute to stress relaxation of the pelvic supporting tissues in female runners. The effects were, however, not consistent across all measures. The observations using intra-vaginal dynamometry suggest that faster pelvic accelerations during running, thus higher ground reaction forces [37], cause the connective tissues within and/or anchoring the PFMs to become less stiff, without negatively influencing their contractile function. However, the area of the LH and the LP length at rest, as measured by ultrasonography, were not affected by the magnitude of the pelvic accelerations, suggesting that tissue changes were related to stress relaxation and not to creep. There was also no evidence that higher pressures measured within the posterior fornix during running were associated with greater changes in BN support or PFM function over the course of the run. While there is evidence of tissue strain after the run (lower BN height, larger LH area) the extent of tissue strain does not appear to be associated with the magnitude of the loading forces experienced during the run. As such, our primary hypothesis was not supported.

Furthermore, our secondary hypothesis was not supported as higher exposure of the pelvic floor to loading was also not associated with greater pad weight gain among those with RI-SUI. Interestingly, there was an inverse relationship between pad weight gain during running and pelvic vector accelerations while running. The underlying mechanisms for this observation remain unclear; runners with RI-SUI might

have adopted running mechanics that reduce vector acceleration to mitigate leakage or running with a soaked incontinence pad may have affected their running mechanics [26]. While minimising pelvic accelerations could offer a strategy to mitigate the extent of pelvic floor stress relaxation experienced during running, this might not impact leakage symptom severity. A case study demonstrated that instructing a participant to reduce vertical loading by running 'more softly' led to a reduction in tibial acceleration, vertical oscillation of her centre of mass, and, ultimately, a reduction in symptoms of urine leakage during running [38]. Increasing cadence/decreasing stride length, improving shock absorption through stronger lower limb muscles or appropriate footwear, and/or reducing running speed, among other biomechanical interventions could reduce pelvic loading [39–41]. Further research is necessary to evaluate the effectiveness of biomechanical strategies for mitigating pelvic floor loading and associated reductions in urine leakage.

Bladder neck height at rest and its elevation on MVC prior to the run significantly influenced BN height in standing position and change of position in BN height attained on MVC after the run, while the extent of pelvic floor loading (peak PFSP and pelvic accelerations) did not. A higher BN position before running appears to allow for more descent of the BN during the run. A potential explanation could be that a lower BN at rest might indicate that the supportive structures of the BN are already in an elongated position prior to the run, thus the tissues may be closer to their maximum strain, leaving them less room for descent in these women compared to those whose BN is located higher in the pelvis before the run [14].

Middlekauf et al. [42] reported no differences in maximal vaginal descent, vaginal resting pressure and maximal and mean PFM strength between a group of nulliparous females who completed a strenuous exercise protocol and those who completed a nonstrenuous (walking) exercise protocol. Assuming that the participants who completed the strenuous protocol experienced higher loads on their pelvic floor compared to the nonstrenuous protocol, their finding is consistent with the results of the current study; both suggest that the magnitude of peak or cumulative loading during exercise is not strongly associated with changes in PFM structure or function that occur due to the exercise. Indeed, previous research has demonstrated that approximately 50% of the variability in urethral mobility among females can be attributed to genetic factors [43], thus it is quite possible that intrinsic factors such as genetics may predispose some runners to greater loss of BN support than others, regardless of pelvic loading exposure during running. Our results and those of Middlekauf et al. [42] suggest that intrinsic contributors to the loss of pelvic organ support during running should be investigated in future work.

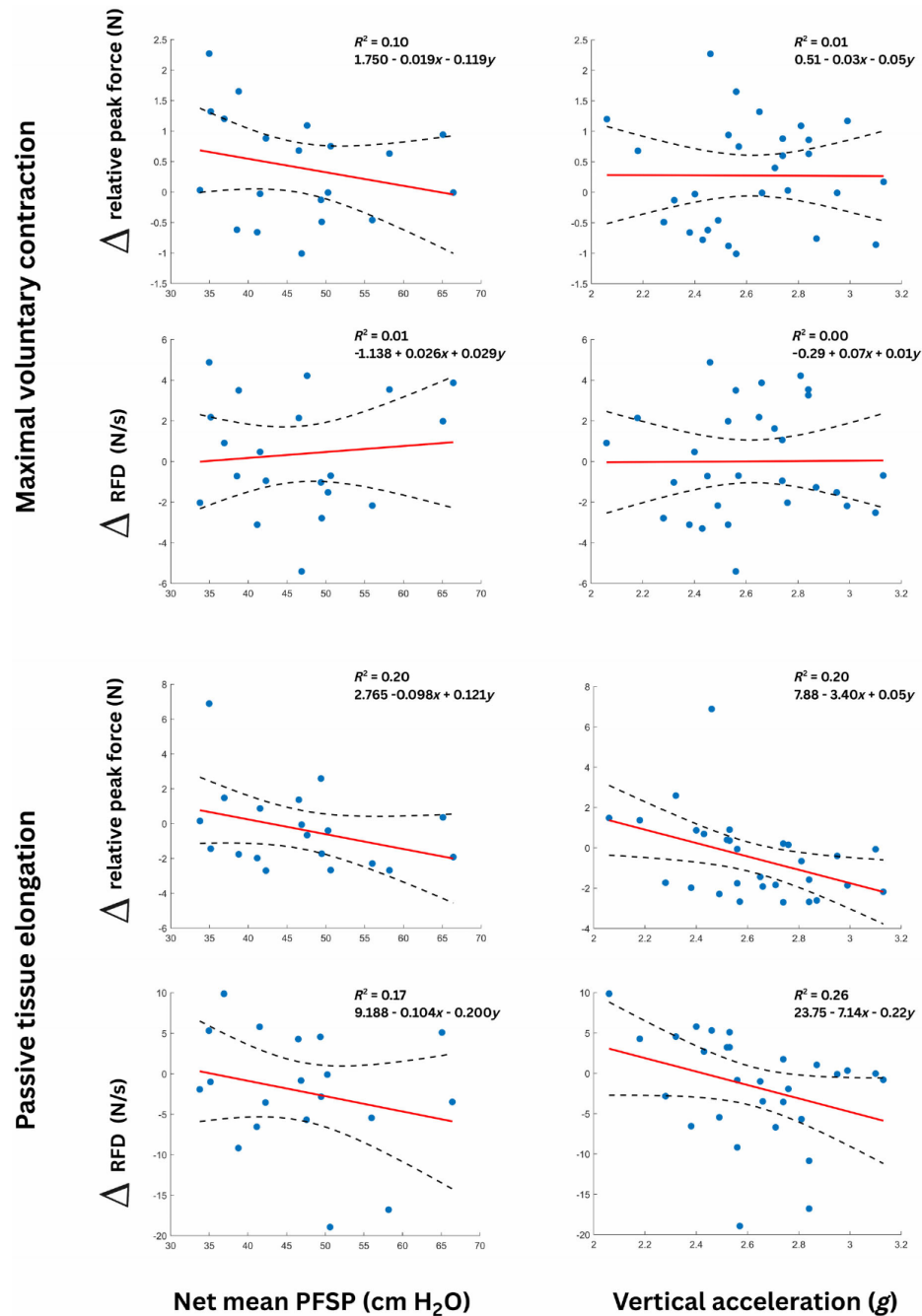
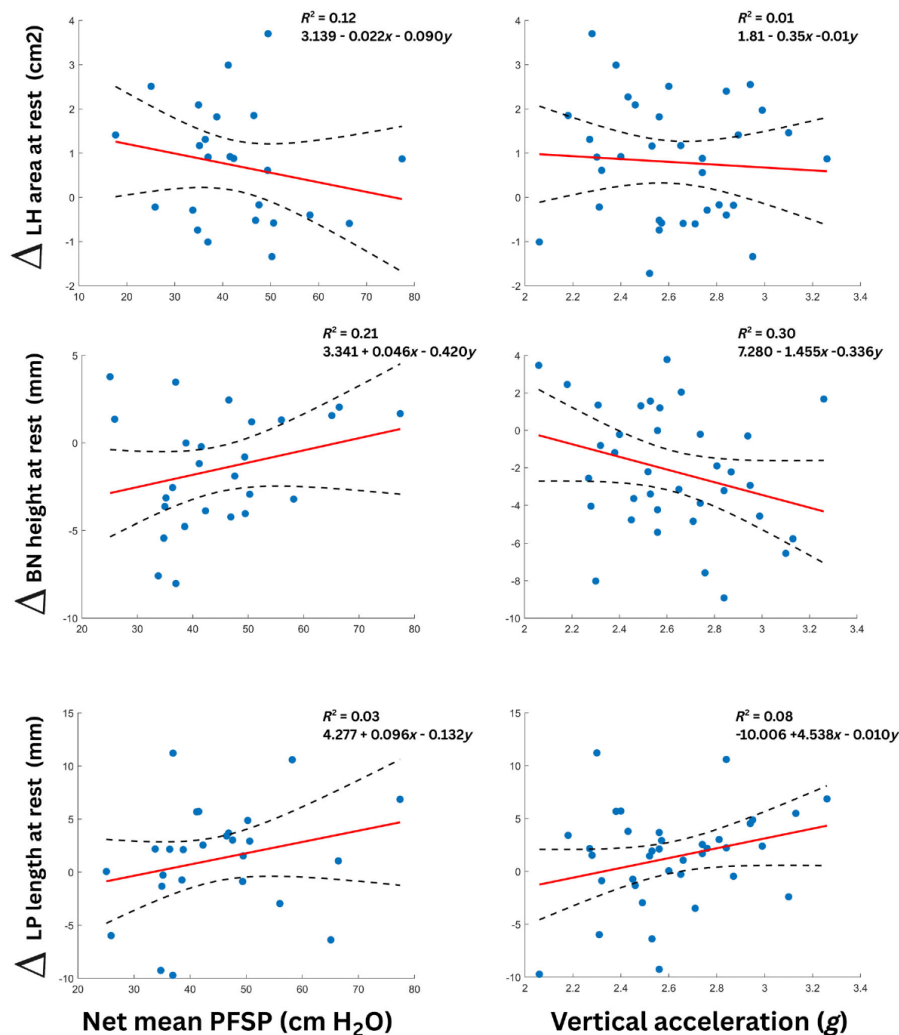


Fig. 1 Scatterplots of the change in relative peak force and rate of force development (RFD) during maximal voluntary contraction (four upper panels) and during passive tissue elongation (four lower panels) after the run in relationship with pelvic floor loading (left: net mean posterior fornix sensor pressure [PFSP]; right: vertical accelerations) measured during the run. The regression lines and their 95% CIs are depicted. The equations are in the form $B_0 + B_1x + B_2y$, where B_0 is the intercept, B_1 is the coefficient associated with the measure of pelvic floor loading and B_2 is the coefficient associated with the baseline value of the pelvic floor muscle outcome indicated. Δ , change; g , gravitational unit; N/s, Newtons per second; N, Newtons; R^2 , coefficient of determination.

Fig. 2 Scatterplots of the change in levator hiatus (LH) area at rest, bladder neck (BN) at rest and levator plate (LP) length after the run in relationship with pelvic floor loading (left: net mean posterior fornix sensor pressure [PFSP]; right: vertical accelerations) measured during the run. The regression lines and their 95% CIs are depicted. The equations are in the form $B_0 + B_1x + B_2y$, where B_0 is the intercept, B_1 is the coefficient associated with the measure of pelvic floor loading and B_2 is the coefficient associated with the baseline value of the pelvic floor muscle outcome indicated. Δ , change.



Measurement of Pelvic Floor Loading

Both the vertical component of pelvic accelerations and the overall vector accelerations were associated with reduced stiffness in the PFMs observed after the run. While pelvic accelerations are highly correlated with ground reaction forces [37], it is not yet known how ground reaction forces are transmitted to the pelvic floor. Similar to the findings of this study, a recent study found no association between running kinetics or pelvic accelerations and symptoms of pelvic floor dysfunction in a sample of postpartum runners [17].

The pelvic floor is a multiplanar network of soft tissues that is subjected to loading through the vertical oscillations of the abdominal and pelvic contents. Intra-vaginal accelerometry may offer a direct means of measuring pelvic floor kinematics to improve our understanding of pelvic floor loading [44]. It appears that a history of vaginal childbirth may impact the capacity of the pelvic floor tissues to dampen pelvic floor oscillations [44]. Further investigation is warranted to understand not just the magnitude of loads to which the pelvic floor is exposed, but the response of the pelvic floor to those loads.

While the pressure sensor used in this work has been validated as an indirect means of measuring IAP during activities [18–22], when worn during physical activities performed in an upright position, pressure measured by a sensor placed in the posterior fornix of the vagina measures the summed forces acting to compress the sensor. Gravitational loading from the abdominal/pelvic contents and inertial loading from reaction forces likely contribute the majority of the compressive forces acting on the sensor during high impact activities. A previous study found a strong positive correlation between net mean peak PFSP and pelvic accelerations during walking ($r = 0.7220$) [18]. In contrast, weaker correlations were observed during running ($r = 0.347$) [45], further demonstrating that inertial loading appears to influence the PFSP. The signal processing methods used here removed any offset related to static gravitational loading and reflected loads during running that were between 27.8% and 99.8% of the pressure recorded during a vertical jump. While previous studies have referred to this pressure as IAP, we chose the more accurate term of PFSP to encompass the multidirectional and summative forces acting on the sensor, which largely represents loads experienced by the pelvic floor. The results of this study suggest that pelvic floor loading measured through PFSP is not associated with the extent of strain observed in the pelvic organ support structures after the run and is not associated with the amount of urine leaked.

This study has some limitations. As our sample lacked diversity, the findings of this research are representative of

White, experienced runners. They are also specific to treadmill running and may not be translatable to other types of high-impact activities. Due to the exploratory nature of this study, we investigated several outcomes and did not use alpha adjustments to account for the multiple outcomes, which may be considered a limitation. Indeed, alpha correction is not required when outcomes are independent [46], however, the five measures used to infer pelvic floor loading were dependent. We chose to include all measures as they each represent different contexts of pelvic floor loading and thus had the capacity to inform on different aspects of the biomechanical influences on the tissues. There was large variance in the PFSP data, which may have influenced our ability to detect meaningful relationships between PFSP and pelvic morphometry and PFM function.

Ideally a multivariable regression analysis would be used, however, due to the small sample size, the regression models were limited to two independent variables. However, other factors such as continence status, body mass index, parity, age, running mechanics, and weekly running distance may also contribute to the influence of pelvic floor loading on pelvic morphometry and PFM function. Adding these potential confounders would require a sixfold increase in the sample size, which was not feasible for this exploratory study. Future studies should explore the influence of these characteristics on running-induced changes in pelvic morphometry and PFM function.

Hardware issues with IAP sensor ($n = 5$) and sensor dislodgement ($n = 6$) contributed to us having substantive data loss for the PFSP measures. Changes in pelvic floor morphometry induced by vaginal birth was likely the primary reason for this. While this same sensor has been widely used during dynamic physical activity performed by parous females, in this study, we measured PFSP over a longer bout of exercise, which might explain why dislodging of the sensor has not previously been reported as a problem. In future work, use of a sensor that is better able to be retained within the posterior fornix, or perhaps a device located in the stomach or rectum, would provide more robust data.

Previous research has shown that compressive shorts can provide pelvic organ support and relieve SUI [47] and as such, we opted to standardise the pants that the participants wore during running. These pants did not provide substantive abdominopelvic compression, however, the vaginal sensor itself and the lycra pants might have interfered with study outcomes.

Based on the outcomes of this study, there remains limited evidence to support advice for women with athletic incontinence to refrain from running as a form of exercise, or to change their running mechanics to reduce pelvic floor loading. Such advice could lead to kinesiphobic behaviours, which may, in turn, result in adverse health consequences associated with inactivity. Urinary symptoms themselves are a

significant barrier to regular, sustained, and intense exercise [26]. This can, in turn, contribute to decreased physical fitness and overall wellbeing [26]. Much work is still needed before biomechanical interventions should be recommended. Future studies should aim to incorporate robust biomechanical data with tools to assess pelvic floor morphometry and function to better understand how different movement patterns or loading conditions impact female pelvic health. Longitudinal studies are also needed to assess the long-term impact of loading on the pelvic floor. Additionally, further research is still needed to explore how conservative management strategies could benefit individuals with athletic incontinence.

In conclusion, although no significant correlations were found between pelvic loading exposure during a run and changes in PFM contractile strength after the run, higher pelvic skeletal accelerations were associated with greater loss in passive stiffness of the paravaginal tissues after the run. Intrinsic factors may influence reductions in pelvic organ support induced by loading exposure and should be investigated.

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Disclosure of Interests

The authors certify that they have no affiliations with or financial involvement in any organisation or entity with a direct financial interest in the subject matter or materials discussed in the article.

Ethics Statement

The study protocol was approved by the Health Sciences and Sciences Research Ethics Board of the University of Ottawa. The participants provided written informed consent prior to participating in the protocol.

Author Contributions

All authors were fully involved in the design of the study, and in the preparation of this manuscript. Under the mentorship of Dr. McLean, Ms. Berube was primarily responsible for collecting data and preparing the original draft. All authors contributed to the revision process and provided final approval prior to this submission.

Data Availability Statement

Data may be requested from the corresponding author.

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