THE INFLUENCE OF POSTURE ON PELVIC FLOOR MUSCLE ACTIVATION AND SENSORY AWARENESS IN WOMEN WITH AND WITHOUT STRESS URINARY INCONTINENCE

by

Cindy Christine Auchincloss

A thesis submitted to the Graduate Program in Rehabilitation Science

In conformity with the requirements for

the degree of Doctor of Philosophy

Queen's University

Kingston, Ontario, Canada

December 2023

Abstract

The integration of the sensory and motor systems is essential to optimal motor control. Despite the importance of the pelvic floor muscles (PFMs) to continence control and the successful use of PFM training to improve continence function, the sensory awareness of the PFMs has not been evaluated. The aims of this dissertation were to evaluate neuromuscular activation and sensory awareness of the PFMs in women with and without stress urinary incontinence and to examine the potential for position changes to alter sensorimotor function. Three studies were conducted from a single sample comprising continent women and women with mild and moderate stress urinary incontinence (SUI), as determined through a validated questionnaire. PFM electromyographic (EMG) signals were recorded at rest and during PFM maximum voluntary contractions (MVCs) performed in different positions and postures. During each MVC, participants rated their awareness of their PFMs contracting using a visual analog scale (VAS). Sensorimotor function was compared among the groups and among positions within each group. The relationship between PFM activation and sensory awareness of activation was determined using correlation analyses. Overall, sensorimotor function of the PFMs was lower in women with SUI. The group of women with moderate SUI generated the lowest amplitudes of PFM activity during MVCs and was the only group with lower maximal activation recorded in standing compared to lying. Changing positions influenced PFM activation and awareness, although the impact of position was inconsistent among the positions and groups. Those with SUI rated their sensory awareness lower than continent women; women with mild symptoms reported the lowest awareness. Further, when lying down, sensory awareness was not associated with PFM performance in women with SUI, and when standing the relationship between PFM activation and awareness was poor for all women. These findings suggest that PFM awareness may be compromised in women with SUI and neuromuscular activation is impaired among women with

moderate SUI symptoms but not mild symptoms. What women report that they “feel” when their PFMs are contracting, may not reflect what the PFMs are doing. The results of this research suggest that verification of a correct PFM contraction is necessary when training the PFMs.

Co-Authorship

This dissertation contains material from three manuscripts. Preliminary results from Chapter 3 and from Chapter 4 were presented at the Canadian Physiotherapy Association Congress in Montreal, QC (May 25, 2013). The material in Chapter 3, Chapter 4, and Chapter 5 will be prepared for submission for publication. Authorship is as follows:

Chapter 3: Auchincloss, C., McLean, L. Neutral lumbopelvic postures enhance pelvic floor muscle activation in women with urinary incontinence. Canadian Physiotherapy Association Congress, Montreal, QC, May 25, 2013. (Podium Presentation).

Chapter 4: Auchincloss, C., McLean, L. Hip position enhances involuntary but not voluntary pelvic floor muscle activation in women with urinary incontinence. Canadian Physiotherapy Association Congress, Montreal, QC, May 25, 2013. (Podium Presentation).

Chapter 3: Auchincloss, C., Pukall, C., McLean, L. The influence of posture on pelvic floor muscle activation in women with and without stress urinary incontinence. In preparation.

Chapter 4: Auchincloss, C., Pukall, C., McLean, L. The effect of hip position on pelvic floor muscle activation in women with and without stress urinary incontinence. In preparation.

Chapter 5: Auchincloss, C., Pukall, C., McLean, L. Pelvic floor muscle awareness is lower in women with stress urinary incontinence compared to women without urinary incontinence. In preparation.

Cindy Auchincloss was the primary author of all the chapters within the thesis. For each chapter, C. Auchincloss conceptualized and designed the research under the mentorship of co-supervisors Dr. Linda McLean and Dr. Caroline Pukall. C. Auchincloss acquired the data, analyzed the data, and interpreted the results under the guidance of Dr. Linda McLean. C. Auchincloss drafted all chapters and made revisions based on input and feedback from the co-supervisors.

Acknowledgements

I would like to express my sincere gratitude to all the people who have supported and believed in me throughout my PhD journey. First and foremost, I could not have reached this moment in time without my supervisor, Dr. Linda McLean. I thank her for her invaluable guidance, her vast knowledge, and her amazing ability to get things done. Without her understanding and grace, this thesis would never have come to fruition. I also thank my co-supervisor, Dr. Caroline Pukall, for her constructive comments, heartfelt encouragement, and suggestions that helped me improve the quality of this work. I am grateful to the faculty at the School of Rehabilitation Therapy over the years that have inspired me to ask questions and to search for answers. My enthusiasm for research was shaped by the passion and leadership demonstrated by Dr. Elsie Culham, Dr. Cheryl King Van Vlack, Ms. Liz Tata, Dr. Linda McLean, and Dr. Kathleen Norman.

I owe a special thanks to my beautiful circle of friends and my talented pelvic health therapists who work for KPH. Collectively, they have stood beside me through the highs and lows of this adventure. They have provided me with unconditional emotional and moral support throughout the process. I especially thank Martine, Nicole, Stephanie, Kristina, Rhonda, Tarra, Amy, Peter, Diana, Brittany, Sarah, Kara, Maura, Erlyn, and Bev for their friendship, collaboration, and love. They have made this experience enjoyable and rewarding, tolerable and less painful!

Finally, I thank my family for their unconditional love, patience, and understanding. They have always been there for me in good and bad times. I dedicate this dissertation to my parents, who have taught me the value of perseverance, humility, and hard work. I also dedicate it to my partner, Kevin, who has been my rock and my biggest cheerleader. And finally, I dedicate it to my children Josh, Sadie, Ethan, and Zac who have each contributed to my dedication and

perseverance. I thank you with a full heart for standing next to me with praise and support. You are and always will be the joy of my life and the reason for everything I do.

Physiotherapy is both an art and a science. Although my mentors and teachers have cultivated a rich understanding of the science of physiotherapy in me, it has been my patients that have taught me, and continue to teach me, the delicate art of physiotherapy. Health and healing are built on the intersection of a deep understanding of science and full appreciation of the art of rehabilitation.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

Ag-AgCl	Silver-Silver Chloride
ATFP	Arch of the pelvic fascia
ALTA	Arch of the levator ani
BMI	Body mass index
cm	Centimeters
CONT	Continent
CSA	Cross sectional area
DSE	Differential suction electrode
EMG	Electromyography
Hyper	Hyperlordosis
Hypo	Hypolordosis
ICIQ-UI SF	International Consultation on Incontinence Questionnaire – Urinary Incontinence Short Form
IAP	Intra-abdominal pressure
ICC	Inter-class correlation coefficient
IIQ-7	Incontinence Impact Questionnaire-7
IQR	Interquartile range
LAMs	Levator ani muscles
LR	Lateral rotation
MD	Meaningful difference
µV	Microvolt

mm	Millimeters
MMT	Manual muscle test
MOD	Moderate
MOS	Modified Oxford Scale
MR	Medial Rotation
MVC	Maximum voluntary contraction
PFM	Pelvic floor muscle
PFMT	Pelvic floor muscle training
QOL	Quality of life
RMS	Root mean square
SD	Standard deviation
SEM	Standard error of the measurement
SUI	Stress urinary incontinence
TKA	Total hip arthroscopy
UDI-6	Urinary Distress Inventory-6
UDS	Urodynamic studies
USI	Ultrasound imaging
VAS	Visual analog scale

Chapter 1

Introduction

1.1 Stress Urinary Incontinence

Urinary incontinence (UI) is defined as the involuntary leaking of urine (1). The prevalence of UI in women appears to rise during the childbearing years and again after menopause (2, 3). It has been estimated that 50% of women will experience UI at some point during their life (4, 5). UI can lead to reduced participation in social and physical activities (6), it can negatively impact quality of life (QOL) (7), and it is one of the leading causes of nursing home admissions in the United States (6, 8). The economic costs associated with UI are high for individuals and public health care. The Canadian Continence Foundation estimates that the total personal expenditure of Canadians affected by UI is 2.6 billion dollars annually. At the same time, UI costs the Canadian healthcare system 3.8 billion annually (9).

Stress urinary incontinence (SUI) is the most common type of UI among women, and it is estimated that half of women with UI have SUI (10). SUI is defined as the complaint of unintentional leakage of urine during movements or activities that increase intra-abdominal pressure (IAP), such as coughing, laughing, sneezing, jumping, lifting and specific exercises (11). When bladder pressure suddenly rises in response to an increase in IAP, and exceeds urethral closure pressure, urine leaks from the urethra. According to the Canadian Urinary Bladder Survey completed in 2012, the prevalence of SUI in Canadian women over 40 is 33% (12). Prevalence rates vary substantially between

10% and 77%, and it is thought that rates are often underestimated when surveying women (10). It is also estimated that only one-quarter of those with continence issues discuss symptoms with their physician (13-15).

1.2 Pelvic Floor Muscle Training

Physiotherapy interventions based on pelvic floor muscle training (PFMT) have been established as a cost-effective and successful conservative treatment option for women with all types of UI (10). PFMT is a form of exercise therapy that aims to improve continence control by optimizing pelvic floor muscle (PFM) function, including exercises involving a combination of PFM strength, endurance, power, and relaxation (16). While physiotherapy interventions are broader than PFMT alone, including individualized exercises, education, and behavioural interventions, PFMT is recommended as a first-line conservative treatment option for SUI (10).

The ability to perform an effective PFM contraction is a critical factor in the success of PFMT. A correct PFM contraction can be defined as one where, upon contraction, the PFMs move in an anterior and cranial direction such that urethral closure pressure can be enhanced through external compression, and the urethra and bladder neck are supported in an optimal position to support urethral closure (17, 18). Impairments in PFM function have been reported in the literature in women with SUI in the form of reduced strength (19), decreased endurance (19), lower rate of force production (20), and altered motor control (21-26).

There is evidence that approximately 30% of women are unable to do an effective PFM (27-30), and that, in some cases, sensory awareness of the PFMs may be compromised (19, 23, 31). Despite the importance of sensory feedback to the motor learning process, the concept of sensory awareness in the PFMs has yet to be thoroughly examined.

1.3 The Influence of Posture and Position on PFM Sensorimotor Function

Much attention has been given to understanding the influence of body position and posture on PFM function (32-41). The PFMs are under voluntary and involuntary control (42). They function in synergy with many muscles around the lumbopelvic area through a complex network of fascia and connective tissue (23, 43-46), and they close off the pelvic outlet in the transverse plane (47); thus, the PFMs have potential to be influenced by body position and posture. Out of convenience and/or based on attempts at progression, PFM exercises are prescribed to be performed in various postures and positions. While, as noted above, the literature has explored the effect of body position and lumbopelvic posture on various aspects of PFM function, the effects are not clear, and the impact of changing body position and posture on the sensory awareness of the PFMs is unknown (32, 33, 40, 41, 48). The effect of hip flexion and rotation on PFM activation and awareness has also yet to be adequately explored despite emerging evidence of a relationship between these two muscle groups (45, 49-51).

1.4 Dissertation Objectives

To address these gaps in the literature, I employed a cross-sectional, observational study design. A single sample of women with and without SUI was recruited to participate in one comprehensive protocol to achieve the following main objectives:

1) Compare PFM activation at rest (tonic activation) and with maximal effort voluntary contractions (maximal activation) among women with and without SUI while they assumed different body positions (Chapter 3), lumbopelvic postures (Chapter 3) and hip positions (Chapter 4).
2) Determine if tonic and maximal PFM activation is influenced by body position (lying vs standing, Chapter 3), hip position (hip flexion vs rotation, Chapter 4), and lumbopelvic posture (neutral vs hypolordosis vs hyperlordosis, Chapter 3) in continent women and those with mild and moderate SUI symptoms.
3) Determine if PFM sensory awareness is compromised in women with SUI using visual analog scales (VASs) to quantify sensory awareness of the PFMs contracting (Chapter 5). Then, compare PFM awareness among women who are continent and those with mild and moderate SUI in different test positions (Chapter 5).
4) Examine the accuracy of perceived PFM awareness in women with and without stress urinary incontinence by investigating the relationship between PFM activation and sensory awareness using correlation analyses (Chapter 5).
5) Determine if sensory awareness of PFM contraction is altered when women assume different body positions, hip positions, and lumbopelvic postures (Chapter 5).

1.5 Dissertation Hypotheses

The overall hypotheses of this dissertation were that PFM activation and sensory awareness would be compromised in women with mild and moderate SUI relative to continent women and that PFM activation and awareness would be influenced by body position, hip position, and lumbopelvic posture.

Specific hypotheses for each objective were:

1. Tonic and maximal PFM activation will be different among women with mild and moderate SUI compared to women without SUI symptoms.
2. Body position, hip position, and lumbopelvic posture will affect tonic and maximal PFM activation differently in women with and without SUI.
3. PFM awareness will be altered in women with SUI compared to women without SUI.
4. The relationship between PFM activation and sensory awareness will depend on continence status and position. Women without SUI symptoms will demonstrate a strong association between activation and awareness, whereas the association between activation and PFM awareness in those with mild and moderate SUI will be low.
5. PFM awareness will be altered by body position, hip position, and lumbopelvic posture, where the effect of the position will depend on continence status and severity of symptoms.

References

1. D'Ancona C, Haylen B, Oelke M, Abranches-Monteiro L, Arnold E, Goldman H, et al. The International Continence Society (ICS) report on the terminology for adult male lower urinary tract and pelvic floor symptoms and dysfunction. Neurourol Urodyn. 2019;38(2):433-77.

2. Lukacz ES, Santiago-Lastra Y, Albo ME, Brubaker L. Urinary Incontinence in Women: A Review. JAMA. 2017;318(16):1592-604.

3. Hunskaar S, Arnold EP, Burgio K, Diokno AC, Herzog AR, Mallett VT. Epidemiology and natural history of urinary incontinence. Int Urogynecol J Pelvic Floor Dysfunct. 2000;11(5):301-19.

4. Abufaraj M, Xu T, Cao C, Siyam A, Isleem U, Massad A, et al. Prevalence and trends in urinary incontinence among women in the United States, 2005-2018. Am J Obstet Gynecol. 2021;225(2):166 e1- e12.

5. Milsom I, Gyhagen M. The prevalence of urinary incontinence. Climacteric. 2019;22(3):217-22.

6. Hannestad YS, Rortveit G, Sandvik H, Hunskaar S, Norwegian EsEoIitCoN-T. A community-based epidemiological survey of female urinary incontinence: the Norwegian EPINCONT study. Epidemiology of Incontinence in the County of Nord-Trondelag. J Clin Epidemiol. 2000;53(11):1150-7.

7. Kwon BE, Kim GY, Son YJ, Roh YS, You MA. Quality of life of women with urinary incontinence: a systematic literature review. Int Neurourol J. 2010;14(3):133-8.

8. Morrison A, Levy R. Fraction of nursing home admissions attributable to urinary incontinence. Value Health. 2006;9(4):272-4.

9. Institute C. The Impact of Incontinence in Canada A Briefing Document for Policy Makers 2014 [Available from: https://www.canadiancontinence.ca/pdfs/en-impact-of-incontinence-in-canada-2014.pdf.

10. Dumoulin C, Cacciari LP, Hay-Smith EJC. Pelvic floor muscle training versus no treatment, or inactive control treatments, for urinary incontinence in women. Cochrane Database Syst Rev. 2018;10:CD005654.

11. Haylen BT, de Ridder D, Freeman RM, Swift SE, Berghmans B, Lee J, et al. An International Urogynecological Association (IUGA)/International Continence Society (ICS) joint report on the terminology for female pelvic floor dysfunction. Neurourol Urodyn. 2010;29(1):4-20.

12. Herschorn S, Gajewski J, Schulz J, Corcos J. A population-based study of urinary symptoms and incontinence: the Canadian Urinary Bladder Survey. BJU Int. 2008;101(1):52-8.

13. Hunskaar S, Lose G, Sykes D, Voss S. The prevalence of urinary incontinence in women in four European countries. BJU Int. 2004;93(3):324-30.

14. Anderson KM, Davis K, Flynn BJ. Urinary incontinence and pelvic organ prolapse. Med Clin North Am. 2015;99(2):405-16.

15. Melville JL, Katon W, Delaney K, Newton K. Urinary incontinence in US women: a population-based study. Arch Intern Med. 2005;165(5):537-42.

16. Bo K, Frawley HC, Haylen BT, Abramov Y, Almeida FG, Berghmans B, et al. An International Urogynecological Association (IUGA)/International Continence Society (ICS) joint report on the terminology for the conservative and nonpharmacological management of female pelvic floor dysfunction. Int Urogynecol J. 2017;28(2):191-213.

17. Bo K, Lilleas F, Talseth T, Hedland H. Dynamic MRI of the pelvic floor muscles in an upright sitting position. Neurourol Urodyn. 2001;20(2):167-74.

18. DeLancey JO. Structural aspects of the extrinsic continence mechanism. Obstet Gynecol. 1988;72(3 Pt 1):296-301.

19. Devreese A, Staes F, De Weerdt W, Feys H, Van Assche A, Penninckx F, et al. Clinical evaluation of pelvic floor muscle function in continent and incontinent women. Neurourol Urodyn. 2004;23(3):190-7.

20. Morin M, Bourbonnais D, Gravel D, Dumoulin C, Lemieux MC. Pelvic floor muscle function in continent and stress urinary incontinent women using dynamometric measurements. Neurourol Urodyn. 2004;23(7):668-74.

21. Madill SJ, Harvey MA, McLean L. Women with SUI demonstrate motor control differences during voluntary pelvic floor muscle contractions. Int Urogynecol J Pelvic Floor Dysfunct. 2009;20(4):447-59.

22. Devreese A, Staes F, Janssens L, Penninckx F, Vereecken R, De Weerdt W. Incontinent women have altered pelvic floor muscle contraction patterns. J Urol. 2007;178(2):558-62.

23. Thompson JA, O'Sullivan PB, Briffa NK, Neumann P. Altered muscle activation patterns in symptomatic women during pelvic floor muscle contraction and Valsalva manouevre. Neurourol Urodyn. 2006;25(3):268-76.

24. Smith MD, Coppieters MW, Hodges PW. Postural activity of the pelvic floor muscles is delayed during rapid arm movements in women with stress urinary incontinence. Int Urogynecol J Pelvic Floor Dysfunct. 2007;18(8):901-11.

25. Smith MD, Coppieters MW, Hodges PW. Postural response of the pelvic floor and abdominal muscles in women with and without incontinence. Neurourol Urodyn. 2007;26(3):377-85.

26. Smith MD, Coppieters MW, Hodges PW. Is balance different in women with and without stress urinary incontinence? Neurourol Urodyn. 2008;27(1):71-8.

27. Kegel AH. The nonsurgical treatment of genital relaxation; use of the perineometer as an aid in restoring anatomic and functional structure. Ann West Med Surg. 1948;2(5):213-6.

28. Kegel AH. Stress incontinence and genital relaxation; a nonsurgical method of increasing the tone of sphincters and their supporting structures. Ciba Clin Symp. 1952;4(2):35-51.

29. Bo K, Sherburn M. Evaluation of female pelvic-floor muscle function and strength. Phys Ther. 2005;85(3):269-82.

30. Dietz HP, Wilson PD, Clarke B. The use of perineal ultrasound to quantify levator activity and teach pelvic floor muscle exercises. Int Urogynecol J Pelvic Floor Dysfunct. 2001;12(3):166-8; discussion 8-9.

31. Uechi N, Fernandes A, Bo K, de Freitas LM, de la Ossa AMP, Bueno SM, et al. Do women have an accurate perception of their pelvic floor muscle contraction? A cross-sectional study. Neurourol Urodyn. 2020;39(1):361-6.

32. Capson AC, Nashed J, McLean L. The role of lumbopelvic posture in pelvic floor muscle activation in continent women. J Electromyogr Kinesiol. 2011;21(1):166-77.

33. Chen CH, Huang MH, Chen TW, Weng MC, Lee CL, Wang GJ. Relationship between ankle position and pelvic floor muscle activity in female stress urinary incontinence. Urology. 2005;66(2):288-92.

34. Chen HL, Lin YC, Chien WJ, Huang WC, Lin HY, Chen PL. The effect of ankle position on pelvic floor muscle contraction activity in women. J Urol. 2009;181(3):1217-23.

35. Frawley HC, Galea MP, Phillips BA, Sherburn M, Bo K. Effect of test position on pelvic floor muscle assessment. Int Urogynecol J Pelvic Floor Dysfunct. 2006;17(4):365-71.

36. Frawley HC, Galea MP, Phillips BA, Sherburn M, Bo K. Reliability of pelvic floor muscle strength assessment using different test positions and tools. Neurourol Urodyn. 2006;25(3):236-42.

37. Bo K, Finckenhagen HB. Is there any difference in measurement of pelvic floor muscle strength in supine and standing position? Acta Obstet Gynecol Scand. 2003;82(12):1120-4.

38. Halski T, Ptaszkowski K, Slupska L, Dymarek R, Paprocka-Borowicz M. Relationship between lower limb position and pelvic floor muscle surface electromyography activity in menopausal women: a prospective observational study. Clin Interv Aging. 2017;12:75-83.

39. Halski T, Slupska L, Dymarek R, Bartnicki J, Halska U, Krol A, et al. Evaluation of bioelectrical activity of pelvic floor muscles and synergistic muscles depending on orientation of pelvis in menopausal women with symptoms of stress urinary incontinence: a preliminary observational study. Biomed Res Int. 2014;2014:274938.

40. Sapsford RR, Richardson CA, Stanton WR. Sitting posture affects pelvic floor muscle activity in parous women: an observational study. Aust J Physiother. 2006;52(3):219-22.

41. Sapsford RR, Richardson CA, Maher CF, Hodges PW. Pelvic floor muscle activity in different sitting postures in continent and incontinent women. Arch Phys Med Rehabil. 2008;89(9):1741-7.

42. Vodusek DB. Anatomy and neurocontrol of the pelvic floor. Digestion. 2004;69(2):87-92.

43. Kruger J, Budgett D, Goodman J, Bo K. Can you train the pelvic floor muscles by contracting other related muscles? Neurourol Urodyn. 2019;38(2):677-83.

44. Tuttle LJ, DeLozier ER, Harter KA, Johnson SA, Plotts CN, Swartz JL. The Role of the Obturator Internus Muscle in Pelvic Floor Function. Journal of Women's Health Physical Therapy. 2016;40(1):15-9.

45. Underwood DB, Calteaux TH, Cranston AR, Novotny SA, Hollman JH. Hip and pelvic floor muscle strength in women with and without stress urinary incontinence: A ccase-control study. Journal of Women's Health Physical Therapy. 2012;36(1):55-61.

46. Bo K, Stien R. Needle EMG registration of striated urethral wall and pelvic floor muscle activity patterns during cough, Valsalva, abdominal, hip adductor, and gluteal muscle contractions in nulliparous healthy females. Neurourol Urodyn. 1994;13(1):35-41.

47. Gray H. Gray's Anatomy 37th ed. Edinburgh: Churchill Livingstone; 1989.

48. Ptaszkowski K, Paprocka-Borowicz M, Slupska L, Bartnicki J, Dymarek R, Rosinczuk J, et al. Assessment of bioelectrical activity of synergistic muscles during pelvic floor muscles activation in postmenopausal women with and without stress urinary incontinence: a preliminary observational study. Clin Interv Aging. 2015;10:1521-8.

49. Tuttle LJ, Autry T, Kemp C, Lassaga-Bishop M, Mettenleiter M, Shetter H, et al. Hip exercises improve intravaginal squeeze pressure in older women. Physiother Theory Pract. 2020;36(12):1340-7.

50. Jordre B, Schweinle W. Comparing resisted hip rotation with pelvic floor muscle training in women with stress urinary incontinence: A pilot study. Journal of Women's Health Physical Therapy. 2014;38(2):81-9.

51. Marques SAA, Silveira S, Passaro AC, Haddad JM, Baracat EC, Ferreira EAG. Effect of Pelvic Floor and Hip Muscle Strengthening in the Treatment of Stress Urinary Incontinence: A Randomized Clinical Trial. J Manipulative Physiol Ther. 2020;43(3):247-56.

Chapter 2

Literature Review

2.1 Female Stress Urinary Incontinence

Stress urinary incontinence (SUI) is defined by the complaint of involuntary loss of urine with effort or exertion, such as when coughing, laughing, sneezing, and/or performing activities that cause bladder pressure to exceed urethral closure pressure (1). It affects approximately one-third of Canadian women over 40 years of age (2). SUI can have a profound impact on quality of life (QOL) (3), can lead to women limiting their participation in physical activities, and to social isolation and psychological distress (4).

Urinary continence is maintained by the complex interaction of sphincteric and support systems, including the somatic and autonomic systems, adequate neuromuscular control, patent vascular support, and intact connective tissues. The pathophysiology behind the failure of the continence mechanism is multifactorial (5-8), and as such, SUI can result when one or a combination of these structures fails. The pelvic floor muscles (PFMs) are thought to be implicated in SUI (6).

2.2 The Pelvic Floor Muscles

The PFMs span the pelvic outlet forming a diaphragm separating the pelvic cavity from the perineum, through which the urethra, vagina, and anus pass. They include a posterior shelf-like coccygeus muscles, the hammock-like levator ani muscles (LAMs), and the urethral and anal sphincters (9). The bilateral LAMs can be further divided into

individual muscles referred to as the iliococcygeus (IC), the pubococcygeus (PC), and the puborectalis (PR) muscle. As a group, the LAMs provide support to the pelvic viscera and reinforce the sphincteric system with appropriately timed activation to compress the urethra against the anterior vaginal wall, extrinsically enhancing urethral closure (10-12). The medial fibres of the LAMs are aligned anterior to posterior, originating from the pubic rami and attaching to the coccyx and anococcygeal ligament (13). The lateral aspects of the IC muscle have a broad soft tissue connection with the lateral pelvic wall as it connects to the obturator fascia (14). The tendinous arches, known as the tendinous arch of the levator ani (ATLA) and the tendinous arch of the pelvic fascia (ATPF), are thickened, dense connective tissues that originate from the fascia covering the superior portion of the obturator internus muscles and span between the pubic bone and the ischial spine like guy wires to provide a stable lateral anchor for the LAMs (13). Innervation of the LAM is complex, as the autonomic and somatic systems interact via three primary pathways: the pudendal nerve, the levator ani nerve, and the inferior hypogastric plexus (15). The LAMs are innervated primarily by direct branches from the third through fifth sacral nerves (16, 17). As the levator ani contract concentrically, the rectum, vagina, and urethra are drawn towards the pubic bone, the pelvic floor is elevated, and the urogenital hiatus is closed (18). Because the LAMs are under voluntary control, they are an ideal target for rehabilitation and corrective exercises.

The LAMs contain a high density of slow twitch, fatigue-resistant, type I striated muscle fibres (19-21) that support the pelvic viscera and contribute to postural control. Unlike other skeletal muscles, where electrogenic silence is observed during the resting state, the LAMs maintain a basal level (tonic) of activation at rest (22). They also contain

a small proportion of fast-twitch, fatigable, type II striated muscle fibres (19-21). The type II fibres contract quickly and powerfully, supporting the urethrovesical structures, stabilizing the urethra and bladder neck, and augmenting urethral closure pressure in response to rises in intra-abdominal pressure (IAP) (11, 20). The medial portion of the PC muscle has longer fibre lengths (10.45 ± 0.67 cm) compared to those measured in the coccygeus muscle (5.29 ± 0.46 cm), thus the PC muscle has more capacity to shorten when functioning as a stabilizer (23). The average sarcomere length among individual PFMs appears to be much shorter than other skeletal muscles (23, 24). This architectural property enhances the force-generating capacity of the LAMs when the muscles are lengthened, giving them a mechanical advantage when resisting downward pressures. These architectural specifications are ideal considering the functional role of the LAMs to pelvic organ support (23) and the requirement to respond to sudden, sharp rises in IAP with a fast contraction (25).

Deficits in PFM function and motor control impairments are thought to be present in women with SUI (26-31). Strength (32), endurance (32), and rate of force production (29) may be compromised in some women with SUI. PFM fatigue (33, 34), reduced PFM exercise capacity (35), and elements of central fatigue have also been identified in women with SUI (36). Not all women with SUI demonstrate a deficit in PFM performance (37). Women with SUI may adopt a substitution strategy where they recruit the abdominal muscles to a more significant extent than continent women (30, 31, 38) instead of using a local muscle strategy. It has been suggested that the PFMs contribute to postural control (39) and may have a role in lumbopelvic stability (40). They are thought to be activated in a feed-forward manner in anticipation of limb movement (39-41),

postural perturbation (25), and prior to coughing (42, 43). This feed-forward mechanism appears to be altered in women with SUI (37, 43-45). There is evidence that onset of PFM activation can be delayed (25, 44) and that the PFMs do not shorten prior to a cough (37) in some women with SUI. In response to a load-catching task, women with incontinence seem to over-compensate, as they generate higher PFM activation amplitudes in anticipation of catching a load than their continent counterparts (25). Explanations to understand these findings focus on a protective response and higher muscle activity to compensate for other neuromuscular deficits to achieve continence.

2.3 Pelvic Floor Muscle Training

Conservative treatment options for women with SUI include lifestyle modification, protective pads and undergarments, pharmaceutical interventions, pessaries, and exercise therapies; either guided by a physiotherapist trained in pelvic rehabilitation or other health care provider with training in continence care (46). Pelvic floor muscle training (PFMT) has been established as a cost-effective and successful conservative treatment option for women with all types of UI (47). PFMT aims to improve PFM function with specific exercises that target PFM performance characteristics such as strength, endurance, power, and/or relaxation (48). PFM exercises are individually prescribed based on a thorough assessment of the PFMs, and concurrent interventions often include education and behavioral techniques such as bladder training and diet modifications.

2.3.1 History of PFMT

Pelvic floor muscle training goes back many years. Ancient practices and Eastern medicine embraced pelvic floor rehabilitation in their practices, whereas Western medicine was slower to adopt it. In 1936, a British physiotherapist, Margaret Morris, co-authored a book with Minnie Randell describing a specific set of progressive pelvic floor muscle exercises to be used preventatively in the antenatal period and for recovery during the postpartum period (49). Randell later published a book titled “Training for Childbirth: From the Mother's Point of View," where she instructed women to learn to consciously contract their pelvic floor muscles before activities that cause a rise in IAP to prevent leaking urine (50). This advice is similar to our modern-day recommendation of performing “the knack", a pelvic floor muscle contraction before a cough, sneeze, etc. (51). In the late 1940s, Dr. Arnold Kegel, a prominent obstetrician/gynecologist at the time, presented his work to the Western medical community, where he suggested that by performing specific exercises to strengthen the pubococcygeus muscle after a vaginal delivery, women could experience less involuntary leaking of urine and could also decrease vaginal laxity to provide better support to the pelvic organs (52). In 2017, PFMT was defined as exercise to improve PFM function, including strength, endurance, power, relaxation, or a combination of these (48).

Morris, Randell, and Kegel were adamant in their writings that women needed specific instructions to do the exercises correctly and required a certain degree of training with feedback. Kegel postulated that women often needed to learn to identify the proper muscles that needed strengthening. Based on his experience assessing and treating hundreds of women after vaginal delivery, he estimated that approximately one-third of

women were unable to perform a PFM contraction properly (52, 53). Morris and Randell further stated that learning how to teach PFMT exercises correctly could not be done by reading her text alone; attending a course to learn how to teach women to contract the PFMs was imperative (49). These early experts believed that a deficit in PFM awareness was likely present in most women, that addressing this deficit required specific instruction to achieve optimal PFM recruitment, and that subsequent strengthening of the pelvic floor muscles could be highly effective in the management of urinary incontinence and vaginal laxity.

2.3.2 Effectiveness of PFMT

PFMT is highly recommended as a first-line conservative treatment option to manage all types of urinary incontinence with Level 1A evidence (54). In a 2018 systematic review published by the Cochrane Collaboration, PFMT was found to be superior to no treatment or inactive control interventions when addressing SUI, where women in the PFMT groups were reported to be eight times more likely to report cure and six times more likely to report cure or improvement compared to those not assigned to PFMT (47). PFMT has demonstrated improvement or cure rates between 56 and 74% in women with incontinence, with very few documented adverse effects (47). The effects of PFMT can last as long as five (55) and six years (56) after treatment. However, the longer-term effectiveness is still uncertain (47, 57). To optimize effectiveness for the management of SUI symptoms, PFM contractions should be performed accurately and at an appropriate intensity to achieve the desired training goals (58).

Sound biological rationales haves been proposed for why PFMT works, and factors that seem to increase the likelihood of success in a PFMT program have been

identified (47, 59, 60). One critical factor is the ability to do a proper PFM contraction (47, 59). When the PFMs contract correctly, the anorectum is drawn in a ventral and cranial direction (18), and when they contract with sufficient force, the urethra is compressed (61). A randomized controlled trial (RCT) demonstrated that after training women to perform a proper PFM contraction prior to coughing ("a knack"), urine leakage was reduced by 73-98% within one week (51). Contracting correctly, at the right time, with the right amount of force resulted in a substantial, immediate reduction in urine leakage during coughing. However, despite recognizing how vital a correct PFM contraction is to the success of PFMT programs, many women are identified as not being able to perform an effective PFM contraction (32, 52, 53, 62-68). Reports suggest that 14% (67) to 70% (32) of women do not contract their PFMs properly. Verbal instruction and knowledge of PFM anatomy and function may contribute to the correct and effective recruitment of the PFMs (69). However, methods to enhance motor learning to perform an effective PFM contraction have yet to be thoroughly explored.

2.4 The Effect of Posture and Position on PFM Function

The PFMs are mechanically, anatomically, and functionally related to the abdominal (40, 70), lumbar (71-73), and hip (14) muscles. They are thought to be involved in postural control, bladder and bowel function, breathing, sexual function, and supporting the pelvic organs. The influence of position and posture on global PFM function is of importance because of their transverse orientation, the influence of gravitational loading on pelvic organ support (74-76), and the synergistic relationship

between the pelvic floor and lumbopelvic muscles (72, 77, 78). Because of the complex fascial connections between the different lumbopelvic hip muscles and the PFMs (14), it is worth exploring if body position, hip position and lumbopelvic postures can affect PFM activation.

Urinary incontinence is often provoked in upright positions. However, visual inspection of the perineum and clinical examination of PFM function typically occur in supine positions, which, according to participants, is the most comfortable (79, 80). The influence of body position (supine versus standing) on PFM function has been explored using manometry (79, 81-83), vaginal palpation (81, 82), dynamometry (82, 84), imaging techniques (81, 85, 86), and EMG (22, 77, 82). In a small group (n=14) of asymptomatic women, moving from a supine to an erect position increased bladder and urethral pressure (87). Likewise, compared to resting vaginal pressures recorded in supine positions using manometry (79, 81-83) and dynamometry (82, 84), higher resting vaginal pressures were recorded in standing. Because pressure measured in the bladder, urethra, and vagina are higher in standing than supine and we know that the PFMs provide support to the pelvic organs, it makes sense that PFM tonic activation is also higher in standing positions compared to supine positions (82, 88).

Given the findings described above, it seems plausible that motor unit recruitment and force generation may be greater in standing than supine to generate enough force to overcome the additional resistance created by gravity and body weight in standing positions. However, this is not always the case. PFM strength, measured by vaginal palpation, appears to be greater in supine than standing in women without incontinence symptoms (81) and in women with incontinence (82, 83). Using a dynamometer to

measure PFM force generation, Mastwyck et al. (83) and Gimenez et al. (82, 89) detected higher force production during contractions performed in standing compared to supine positions in women with pelvic floor dysfunction. Mixed results have been reported in the literature when manometry techniques have been used to compare PFM function in supine and standing. Vaginal squeeze pressure has been reported to be higher (83, 90), lower (81, 82), and no different (79) in standing positions than supine positions. IAP influences vaginal squeeze pressure measured using dynamometry and manometry; therefore, they do not represent forces generated exclusively by the PFMs. EMG has also been used to examine the influence of body position on maximal PFM activation, where larger activation amplitudes were reported in supine positions compared to standing (82), while others found consistent activation amplitudes in supine and standing (22, 77). Methodological differences between studies and participant variability likely contribute to these inconsistent results.

The influence of subtle changes in position, such as altering lumbopelvic posture, on PFM activation has been explored, where the results have not been consistent nor conclusive (73, 88, 91-102). The position of the pelvic floor relative to the transverse plane depends on the inclination of the pelvis. IAP transmission is also thought to be altered by pelvic tilt (103). In a seated position, Sapsford et al. (73, 102) published two complementary studies examining the effect of sitting posture on tonic PFM activation, first in parous women without pelvic floor dysfunction (73) and then in a follow-up study with parous women with SUI (102). In both studies, tonic PFM activation was higher in postures where lumbar lordosis was more pronounced (upright supported and very tall unsupported sitting) and lower in slumped sitting where the lumbar spine was flexed, and

lumbar lordosis was lost. Sapsford et al. (73, 102) hypothesized that when lumbar lordosis was enhanced in the very tall sitting posture, there was greater demand on the PFMs in response to abdominal muscle activation.

In standing positions, Capson et al. (88) examined abdominal and PFM activity in 16 nulliparous asymptomatic women while they performed different tasks in three lumbopelvic positions: neutral (habitual), anterior pelvic tilt (hyperlordosis) and a posterior pelvic tilt (hypolordosis). Tonic PFM activation was higher in the posterior pelvic tilt posture than in habitual standing. They reported a consistent pattern whereby the highest PFM maximal activation was recorded when tasks (PFM MVC, coughing, bearing down, and during a load-catching task) were performed in participants' habitual postures compared to the hypo- or hyperlordosis postures. Ptaszkowski et al. (100) also reported higher tonic PFM activity when menopausal women (n = 82) performed a posterior pelvic tilt compared to a neutral and an anterior pelvic tilt. However, in contrast with Capson et al. (88), Ptaszkowski et al. (100) reported the highest tonic and maximal PFM activation when in a hypolordotic posture. Halski et al. (101) performed a similar study on postmenopausal women with incontinence and reported no effect of lumbopelvic posture on tonic or maximal PFM activation (n = 16).

The pelvis was tilted either anteriorly or posteriorly to achieve the desired lumbopelvic posture in the studies described above. Abdominal and lumbar muscle recruitment is required to assume and maintain the desired posture. Lumbopelvic postures can also be assumed passively (e.g. through ankle positioning while standing) to isolate the effect of posture from the muscle activation required to hold the posture (91-93, 96, 97, 104). Yet there is controversy over the effect of ankle position on lumbar lordosis (96,

105-107), making the results of these studies challenging to interpret. Recently, Kannan et al. (104) published a meta-analysis on PFM activation and ankle position, with four studies meeting the inclusion criteria (91-93, 108). It was concluded that maximal PFM activation was facilitated in neutral ankle and dorsiflexed positions, suggesting greater PFM recruitment when participants are in a neutral lumbar lordosis or increased lumbar lordosis (104). The need for more consistency among studies pertains to the heterogeneity of participants, research methods, and procedures. Most studies have tended to use commercially available vaginal probes equipped with large surface electrodes, which allow a global measure of activation of the deeper PFMs. However, they may be subject to migration and movement with posture changes (109, 110), and the large electrode surfaces are prone to recording crosstalk (111).

Our understanding of the anatomical connection between the hip and PFMs is expanding (14, 112). Several reports have identified a relationship between the hip and the PFMs (113-120), where fascial connections are integral to this relationship (14). The obturator internus muscle is responsible for hip abduction and external rotation. It works with the other deep external rotator muscles of the hip, sharing their common insertion point on the medial aspect of the femoral condyle (121). The obturator internus closes off the obturator foramen on the inner side of the pelvis and has a broad fascial connection with the LAMs through the obturator fascia (14, 122). The length of the obturator internus muscle is dependent on what position the hip joint is in which is likely to impact the LAMs. The obturator internus muscle elongates when the hip is in medial rotation and also elongates when the hip is flexed beyond 60 degrees (123). When the hip is in lateral rotation the obturator internus muscle is shortened (123). Because of the fascial

connection between the obturator internus and the LAM, it seems plausible that altering hip flexion or rotation position may influence the length and/or tension on the LAMs. In addition, studies have indicated that hip strengthening exercises, in the absence of PFM strengthening, can lead to improved continence (112, 113, 117, 118). Preliminary findings suggest that hip rotation range of motion and strength (abduction and extension) may be compromised in some women with incontinence (114, 124). Despite their anatomical connections and functional relationship, the influence of hip position on PFM activation at rest and during maximal effort contractions has yet to be explored.

2.5 Somatosensory Awareness

Sensory receptors are embedded in the skin, muscles, tendons, fascia, joint capsules, and viscera, with supplemental afferent information detected by the vestibular system and our vision. We rely heavily on vision and vestibular inputs to accurately perceive motor performance, yet these systems do not normally contribute to our perception of PFM performance. Somatosensory information generated when the PFMs contract comes from mechanoreceptors within muscles and surrounding tissues, receptors in the perineal skin, and proprioceptors (muscle spindles and Golgi tendon organs) in the PFMs. Without visual input as a reference point, error detection is more complex, which may affect PFM motor learning. The most basic level of somatosensory processing is the awareness of isolated sensory events, such as sensing pressure, stretch, proprioception, and pain. This level of sensory processing can be evaluated using threshold testing such as quantitative sensory testing (QST), which has been used in the pelvic health literature

to describe genital sensory innervation in asymptomatic (125), those with pelvic organ prolapse (126-128), and in women with sexual dysfunction (129). Force-matching tasks have been recently explored, using instrumented dynamometers to objectively evaluate the sense of proprioception in the PFMs of women with SUI (130, 131). Although these methods provide essential information to enhance our understanding of the integrity and function of discrete sensory input from the PFMs, their application in a clinical setting is limited.

Evidence shows that some women's perception of a PFM contraction is compromised (30, 32, 44, 132-134). Thompson et al. (30) and Devreese et al. (32) observed that some individuals' awareness of the PFMs contracting did not reflect objective measures of PFM performance. Smith et al. (44, 133) hypothesized that altered postural control and balance deficits detected in women with SUI may be present due to loss of proprioceptive inputs impacting motor control. Uechi et al. (134) compared PFM strength assessed by digital palpation to perceived awareness of the strength of contraction and found that perception did not match strength graded using the modified oxford scale (MOS) in 55 out of 82 women (66%). The lack of blinding and subjective nature of the PFM strength assessment means these findings cannot be considered conclusive. Preliminary evidence highlights the need to explore somatosensory awareness of the PFMs in women with SUI further. However, more consistency when defining the sensory constructs is needed, and methods to examine those constructs should be developed.

The construct of sensory awareness explored in this dissertation involves integrating sensory processing from many receptors in and around the PFMs, covering a

broad area where the state of the pelvic floor, past experiences, and knowledge of the PFMs may influence perception. Longo et al. (135) described this level of somatosensory processing as somatoperception, which seemed to match the construct of PFM awareness that was described by Thompson et al. (30) and Devreese et al. (32), except in their work, PFM awareness was described and not quantified. The construct of sensory awareness of the PFMs contracting in this research will be referred to as PFM awareness. The role of the somatosensory system in modulating PFM control has yet to be thoroughly explored.

2.6 Outcome Measures

Contraction of the LAMs results in an upward movement of the pelvic organs, ventral and cranial movement of the perineum, and closure of the urethra, vagina, and anus (18, 136). Evaluating PFM function is challenging due to the anatomical location of the muscles and their non-linear movement pattern. PFM function is typically described by tone, strength, endurance, motor control/coordination, and power. PFM function can be measured using vaginal palpation, manometry, dynamometry, electromyography, ultrasound, and MRI. Each technique provides unique information about the PFMs.

2.6.1 Electromyography

EMG is the assessment of electrogenic activity generated by action potential propagation within a muscle. EMG can be acquired from the skin surface overlying a muscle of interest (surface EMG) or using intramuscular techniques such as concentric needle EMG or fine-wire EMG, where the electrodes are inserted into the muscle. The electromyogram acquired from surface electrodes represents the sum of motor unit activity within the detection area of the electrode. Surface EMG is useful when the regional or global representation of muscle activity is

of interest, not the activity of individual motor units. Surface electrodes can be adhered to the skin on the perineum to record PFM activity. They are minimally invasive and provide information about global muscle function; however, they are also criticized because they are non-selective and carry a high potential for crosstalk contamination (109). Crosstalk contamination describes EMG signals recorded from a muscle or muscles other than the muscle of interest, which are recorded concurrently with and are indistinguishable from signals recorded from the muscle of interest (137). EMG activation of the PFMs can also be recorded using surface electrodes mounted onto devices of varying geometries, inserted into the vagina or anus (30, 44, 88, 109-111, 138). Intra-session reliability when using vaginal probes seems good (109, 110, 139); however, it has low between-day inter-class correlation coefficients (ICCs), high standard of error of the measurement (SEM), and high meaningful difference (MD) scores, suggesting that interpretation of surface EMG recorded using electrodes mounted on intravaginal probes should be made cautiously (139). Crosstalk contamination, movement artifact, and migration of intravaginal probes are also thought to influence the amplitude of the intravaginally recorded EMG signal (109, 110).

EMG has been recorded from the PFMs using surface (25, 30, 32, 35, 40, 77, 88, 138, 140, 141) and intramuscular techniques (22, 70, 138, 142), providing us with valuable information about the neuromuscular function of the PFMs. It has provided insights into PFM motor control, including synergies with closely associated muscles. In this research, my collaborators and I utilized a unique electrode design to mitigate several limitations identified when using commercial intravaginal electrodes to determine if body position, hip position, and lumbopelvic posture influence PFM activation and to evaluate sensory awareness in continent and incontinent women. The differential suction electrode (DSE) was designed to improve quality of EMG signals recorded from the PFMs (111). Its design incorporated smaller detection surfaces and used suction to adhere the

electrode head onto the vaginal wall. These characteristics minimize motion artifact and allow women to move freely while the electrodes are in place. The DSE has been tested in a cohort of young nulliparous women (n = 20), demonstrating excellent between-trial reliability ($ICC_{(3,1)} \geq 0.96$) and moderate between-day reliability ($ICC_{(3,k)} \geq 0.65$) (140), and it appears to be less susceptible to crosstalk compared to a commonly used vaginal probe (111). Compared to the number of data files contaminated with motion artifact during a coughing task when EMG signals were recorded with the commercial Femiscan™ vaginal probe 29.3% (96/328), only 14.4% (49/349) data files were contaminated when the DSE was used (140). In addition, participants in the study rated their acceptance of insertion and use of the DSE as high and their physical comfort with the device during position changes as high (140). To further reduce motion artifact, the DSE was modified for this series of studies such that the small bipolar detection surfaces were recessed, and conductive paste was placed in the recessed compartments. The DSE is barely detectable by the women once it is suctioned onto the vaginal wall, allowing unimpeded evaluation of muscle function with simultaneous measurement of sensory awareness.

2.6.2 Vaginal Palpation

Vaginal palpation measures the active properties of muscle function, such as force, endurance, and power, as well as passive properties, such as resistance to passive stretch and elongation (143). Vaginal palpation is accessible, efficient to perform, and requires minimal equipment. Importantly, vaginal palpation allows the integrity of the connective tissues to be assessed and can be used to evaluate muscle mass, symmetry between the left and right sides, direction of movement, and identification of painful areas. Numeric rating scales and descriptive

scales have been developed to quantify PFM function assessed by vaginal palpation (32, 48, 79, 144-146). Vaginal palpation using the Modified Oxford Scale (MOS) has demonstrated high construct validity (r_s = 0.79 – 0.80) when compared to manometry and has demonstrated moderate to high intra-rater reliability (κ_w = 0.58 – 0.86) (147). Inter-rater reliability has been reported to be moderate to substantial (κ_w = 0.48 – 0.64) (147). When digital muscle testing was performed in different positions, within-session reliability was deemed to be good to very good ((κ = 0.50 – 0.95) (80). It was determined that vaginal palpation was the most appropriate technique for evaluating PFM functional characteristics for this research, such as confirming that volunteers could contract their PFMs during screening and measuring LAM strength and tone. Even though vaginal palpation likely influences perceived awareness and may even enhance an individual's perception of their pelvic floor muscles (62), this portion of the protocol was kept to a minimum to avoid influencing participants' performance and awareness.

2.6.3 Visual Analog Scale

Visual analog scales (VASs) have been used in healthcare for decades and are frequently used to measure pain perception (148, 149). VASs are simple to use, quick to administer, and have been used in urogynecology research to measure the bother associated with pelvic organ prolapse (150) and as a measure of quality of life (46), where they were deemed valid and reliable, respectively. The VAS demonstrated high repeatability (ICCs > 0.90) when utilized to rate bother scores in women with pelvic organ prolapse (151). Given the importance of performing a correct PFM contraction, it is crucial to evaluate the relationship between PFM awareness and activation. The VAS was deemed appropriate for rating PFM awareness for this research.

2.7 Summary

This literature review demonstrates that the PFMs are an important contributor to the continence mechanism and that PFMT can be an effective conservative treatment option to reduce or cure symptoms of SUI. The ability to contract the PFMs properly contributes to success with PFMT, yet many women need help to contract their PFMs properly. There are many gaps in our knowledge around sensory awareness of the PFMs in women with and without SUI. There is also conflicting evidence impeding our understanding of the influence that body position, hip position, and lumbopelvic posture can have on PFM activation and awareness. This dissertation aims to address these gaps.

2.8 Thesis Outline

To address the objectives of the dissertation, one study was conducted based on data collected from a single convenience sample comprising women with and without SUI. Although using a convenience sample limits the generalizability of the results and may introduce sampling bias, the research questions were exploratory in nature; therefore, a convenience sample was deemed appropriate. Chapter 3 explored the influence of body position (lying vs standing) and lumbopelvic posture (neutral vs hypolordosis vs hyperlordosis) on PFM activation and compared activation amplitude among the three cohorts. Chapter 4 examined the effect of hip flexion and hip rotation on PFM activation and compared activation amplitudes among the cohorts in each position. Chapter 5 examined PFM awareness in women with and without SUI. PFM awareness was compared between women with and without SUI and the relationship between PFM awareness and PFM activation was described for each cohort. The impact of altering body position, hip position and lumbopelvic posture on sensory awareness was also

examined for each group of women. Chapter 6 presents a general discussion of the findings of this dissertation, describes implications relevant to pelvic health physiotherapy, and proposes the next steps needed to advance the role of PFMT in managing SUI.

References

1. Haylen BT, de Ridder D, Freeman RM, Swift SE, Berghmans B, Lee J, et al. An International Urogynecological Association (IUGA)/International Continence Society (ICS) joint report on the terminology for female pelvic floor dysfunction. Neurourol Urodyn. 2010;29(1):4-20.

2. Herschorn S, Gajewski J, Schulz J, Corcos J. A population-based study of urinary symptoms and incontinence: the Canadian Urinary Bladder Survey. BJU Int. 2008;101(1):52-8.

3. Kwon BE, Kim GY, Son YJ, Roh YS, You MA. Quality of life of women with urinary incontinence: a systematic literature review. Int Neurourol J. 2010;14(3):133-8.

4. Hannestad YS, Rortveit G, Sandvik H, Hunskaar S, Norwegian EsEoIitCoN-T. A community-based epidemiological survey of female urinary incontinence: the Norwegian EPINCONT study. Epidemiology of Incontinence in the County of Nord-Trondelag. J Clin Epidemiol. 2000;53(11):1150-7.

5. DeLancey JO, Trowbridge ER, Miller JM, Morgan DM, Guire K, Fenner DE, et al. Stress urinary incontinence: relative importance of urethral support and urethral closure pressure. J Urol. 2008;179(6):2286-90; discussion 90.

6. Falah-Hassani K, Reeves J, Shiri R, Hickling D, McLean L. The pathophysiology of stress urinary incontinence: a systematic review and meta-analysis. Int Urogynecol J. 2021;32(3):501-52.

7. Schick E, Dupont C, Bertrand PE, Jolivet-Tremblay M, Tessier J. Predictive value of maximum urethral closure pressure, urethral hypermobility and urethral incompetence in the diagnosis of clinically significant female genuine stress incontinence. J Urol. 2004;171(5):1871-5.

8. Delancey JO. Why do women have stress urinary incontinence? Neurourol Urodyn. 2010;29 Suppl 1(Suppl 1):S13-7.

9. DeLancey JO. Structural support of the urethra as it relates to stress urinary incontinence: the hammock hypothesis. Am J Obstet Gynecol. 1994;170(6):1713-20; discussion 20-3.

10. Ashton-Miller JA, DeLancey JO. Functional anatomy of the female pelvic floor. Ann N Y Acad Sci. 2007;1101:266-96.

11. Ashton-Miller JA, Howard D, DeLancey JO. The functional anatomy of the female pelvic floor and stress continence control system. Scand J Urol Nephrol Suppl. 2001(207):1-7; discussion 106-25.

12. Theofrastous JP, Wyman JF, Bump RC, McClish DK, Elser DM, Robinson D, et al. Relationship between urethral and vaginal pressures during pelvic muscle contraction. The Continence Program for Women Research Group. Neurourol Urodyn. 1997;16(6):553-8.

13. Gray H. Gray's Anatomy 37th ed. Edinburgh: Churchill Livingstone; 1989.

14. Muro S, Nimura A, Ibara T, Chikazawa K, Nakazawa M, Akita K. Anatomical basis for contribution of hip joint motion by the obturator internus to defaecation/urinary functions by the levator ani via the obturator fascia. J Anat. 2023;242(4):657-65.

15. Nyangoh Timoh K, Bessede T, Lebacle C, Zaitouna M, Martinovic J, Diallo D, et al. Levator ani muscle innervation: Anatomical study in human fetus. Neurourol Urodyn. 2017;36(6):1464-71.

16. Barber MD, Bremer RE, Thor KB, Dolber PC, Kuehl TJ, Coates KW. Innervation of the female levator ani muscles. Am J Obstet Gynecol. 2002;187(1):64-71.

17. Eickmeyer SM. Anatomy and Physiology of the Pelvic Floor. Phys Med Rehabil Clin N Am. 2017;28(3):455-60.

18. Bo K, Lilleas F, Talseth T, Hedland H. Dynamic MRI of the pelvic floor muscles in an upright sitting position. Neurourol Urodyn. 2001;20(2):167-74.

19. Gosling JA, Dixon JS, Critchley HO, Thompson SA. A comparative study of the human external sphincter and periurethral levator ani muscles. Br J Urol. 1981;53(1):35-41.

20. Critchley HO, Dixon JS, Gosling JA. Comparative study of the periurethral and perianal parts of the human levator ani muscle. Urol Int. 1980;35(3):226-32.

21. Koelbl H, Strassegger H, Riss PA, Gruber H. Morphologic and functional aspects of pelvic floor muscles in patients with pelvic relaxation and genuine stress incontinence. Obstet Gynecol. 1989;74(5):789-95.

22. Deindl FM, Vodusek DB, Hesse U, Schussler B. Activity patterns of pubococcygeal muscles in nulliparous continent women. Br J Urol. 1993;72(1):46-51.

23. Tuttle LJ, Nguyen OT, Cook MS, Alperin M, Shah SB, Ward SR, et al. Architectural design of the pelvic floor is consistent with muscle functional subspecialization. Int Urogynecol J. 2014;25(2):205-12.

24. Mittal RK, Sheean G, Padda BS, Rajasekaran MR. Length tension function of puborectalis muscle: implications for the treatment of fecal incontinence and pelvic floor disorders. J Neurogastroenterol Motil. 2014;20(4):539-46.

25. Smith MD, Coppieters MW, Hodges PW. Postural response of the pelvic floor and abdominal muscles in women with and without incontinence. Neurourol Urodyn. 2007;26(3):377-85.

26. Luginbuehl H, Baeyens JP, Taeymans J, Maeder IM, Kuhn A, Radlinger L. Pelvic floor muscle activation and strength components influencing female urinary continence and stress incontinence: a systematic review. Neurourol Urodyn. 2015;34(6):498-506.

27. Leitner M, Moser H, Taeymans J, Kuhn A, Radlinger L. Pelvic floor muscle displacement during voluntary and involuntary activation in continent and incontinent women: a systematic review. Int Urogynecol J. 2015;26(11):1587-98.

28. Moser H, Leitner M, Baeyens JP, Radlinger L. Pelvic floor muscle activity during impact activities in continent and incontinent women: a systematic review. Int Urogynecol J. 2018;29(2):179-96.

29. Morin M, Bourbonnais D, Gravel D, Dumoulin C, Lemieux MC. Pelvic floor muscle function in continent and stress urinary incontinent women using dynamometric measurements. Neurourol Urodyn. 2004;23(7):668-74.

30. Thompson JA, O'Sullivan PB, Briffa NK, Neumann P. Altered muscle activation patterns in symptomatic women during pelvic floor muscle contraction and Valsalva manouevre. Neurourol Urodyn. 2006;25(3):268-76.

31. Madill SJ, Harvey MA, McLean L. Women with SUI demonstrate motor control differences during voluntary pelvic floor muscle contractions. Int Urogynecol J Pelvic Floor Dysfunct. 2009;20(4):447-59.

32. Devreese A, Staes F, De Weerdt W, Feys H, Van Assche A, Penninckx F, et al. Clinical evaluation of pelvic floor muscle function in continent and incontinent women. Neurourol Urodyn. 2004;23(3):190-7.

33. Thomaz RP, Colla C, Darski C, Paiva LL. Influence of pelvic floor muscle fatigue on stress urinary incontinence: a systematic review. Int Urogynecol J. 2018;29(2):197-204.

34. Deffieux X, Hubeaux K, Damphousse M, Raibaut P, Sheikh Ismael S, Thoumie P, et al. Perineal neuromuscular fatigue. Ann Readapt Med Phys. 2006;49(6):331-6, 413-7.

35. Burti JS, Hacad CR, Zambon JP, Polessi EA, Almeida FG. Is there any difference in pelvic floor muscles performance between continent and incontinent women? Neurourol Urodyn. 2015;34(6):544-8.

36. Schabrun SM, Stafford RE, Hodges PW. Anal sphincter fatigue: is the mechanism peripheral or central? Neurourol Urodyn. 2011;30(8):1550-6.

37. Antonio FI, Rodrigues MP, Brooks K, Varette K, McLean L. What improvements in levator ani motor function lead to improvement in stress urinary incontinence signs and symptoms in females? Int Urogynecol J. 2022;33(10):2735-47.

38. Madill SJ, Harvey MA, McLean L. Women with stress urinary incontinence demonstrate motor control differences during coughing. J Electromyogr Kinesiol. 2010;20(5):804-12.

39. Hodges PW, Sapsford R, Pengel LH. Postural and respiratory functions of the pelvic floor muscles. Neurourol Urodyn. 2007;26(3):362-71.

40. Sapsford RR, Hodges PW. Contraction of the pelvic floor muscles during abdominal maneuvers. Arch Phys Med Rehabil. 2001;82(8):1081-8.

41. Sjodahl J, Kvist J, Gutke A, Oberg B. The postural response of the pelvic floor muscles during limb movements: a methodological electromyography study in parous women without lumbopelvic pain. Clin Biomech (Bristol, Avon). 2009;24(2):183-9.

42. Luginbuehl H, Baeyens JP, Kuhn A, Christen R, Oberli B, Eichelberger P, et al. Pelvic floor muscle reflex activity during coughing - an exploratory and reliability study. Ann Phys Rehabil Med. 2016;59(5-6):302-7.

43. Dietz HP, Erdmann M, Shek KL. Reflex contraction of the levator ani in women symptomatic for pelvic floor disorders. Ultrasound Obstet Gynecol. 2012;40(2):215-8.

44. Smith MD, Coppieters MW, Hodges PW. Postural activity of the pelvic floor muscles is delayed during rapid arm movements in women with stress urinary incontinence. Int Urogynecol J Pelvic Floor Dysfunct. 2007;18(8):901-11.

45. Deffieux X, Hubeaux K, Porcher R, Ismael SS, Raibaut P, Amarenco G. Pelvic floor muscle activity during coughing: altered pattern in women with stress urinary incontinence. Urology. 2007;70(3):443-7; discussion 7-8.

46. Lukacz ES, Santiago-Lastra Y, Albo ME, Brubaker L. Urinary Incontinence in Women: A Review. JAMA. 2017;318(16):1592-604.

47. Dumoulin C, Cacciari LP, Hay-Smith EJC. Pelvic floor muscle training versus no treatment, or inactive control treatments, for urinary incontinence in women. Cochrane Database Syst Rev. 2018;10:CD005654.

48. Bo K, Frawley HC, Haylen BT, Abramov Y, Almeida FG, Berghmans B, et al. An International Urogynecological Association (IUGA)/International Continence Society (ICS) joint report on the terminology for the conservative and nonpharmacological management of female pelvic floor dysfunction. Int Urogynecol J. 2017;28(2):191-213.

49. Morris M, Randell M. Maternity and Post-operative Exercises in Diagrams and Words. New York: Oxford University Press; 1936.

50. Randell M. Training for childbirth: From the mother's point of view.: Churchill; 1939. 151 p.

51. Miller JM, Ashton-Miller JA, DeLancey JO. A pelvic muscle precontraction can reduce cough-related urine loss in selected women with mild SUI. J Am Geriatr Soc. 1998;46(7):870-4.

52. Kegel AH. Stress incontinence and genital relaxation; a nonsurgical method of increasing the tone of sphincters and their supporting structures. Ciba Clin Symp. 1952;4(2):35-51.

53. Kegel AH. The nonsurgical treatment of genital relaxation; use of the perineometer as an aid in restoring anatomic and functional structure. Ann West Med Surg. 1948;2(5):213-6.

54. Dumoulin C, Hay-Smith J, Habee-Seguin GM, Mercier J. Pelvic floor muscle training versus no treatment, or inactive control treatments, for urinary incontinence in women: a short version Cochrane systematic review with meta-analysis. Neurourol Urodyn. 2015;34(4):300-8.

55. Lagro-Janssen T, van Weel C. Long-term effect of treatment of female incontinence in general practice. Br J Gen Pract. 1998;48(436):1735-8.

56. Glazener CM, Herbison GP, MacArthur C, Grant A, Wilson PD. Randomised controlled trial of conservative management of postnatal urinary and faecal incontinence: six year follow up. BMJ. 2005;330(7487):337.

57. Bo K, Hilde G. Does it work in the long term?--A systematic review on pelvic floor muscle training for female stress urinary incontinence. Neurourol Urodyn. 2013;32(3):215-23.

58. Dumoulin C, Glazener C, Jenkinson D. Determining the optimal pelvic floor muscle training regimen for women with stress urinary incontinence. Neurourol Urodyn. 2011;30(5):746-53.

59. Bo K. Pelvic floor muscle training is effective in treatment of female stress urinary incontinence, but how does it work? Int Urogynecol J Pelvic Floor Dysfunct. 2004;15(2):76-84.

60. Brooks KCL, Varette K, Harvey MA, Robert M, Brison RJ, Day A, et al. A model identifying characteristics predictive of successful pelvic floor muscle training outcomes among women with stress urinary incontinence. Int Urogynecol J. 2021;32(3):719-28.

61. DeLancey JO. Structural aspects of the extrinsic continence mechanism. Obstet Gynecol. 1988;72(3 Pt 1):296-301.

62. Bo K, Sherburn M. Evaluation of female pelvic-floor muscle function and strength. Phys Ther. 2005;85(3):269-82.

63. Kandadai P, O'Dell K, Saini J. Correct performance of pelvic muscle exercises in women reporting prior knowledge. Female Pelvic Med Reconstr Surg. 2015;21(3):135-40.

64. Moen MD, Noone MB, Vassallo BJ, Elser DM, Urogynecology N. Pelvic floor muscle function in women presenting with pelvic floor disorders. Int Urogynecol J Pelvic Floor Dysfunct. 2009;20(7):843-6.

65. Vermandel A, De Wachter S, Beyltjens T, D'Hondt D, Jacquemyn Y, Wyndaele JJ. Pelvic floor awareness and the positive effect of verbal instructions in 958 women early postdelivery. Int Urogynecol J. 2015;26(2):223-8.

66. Szumilewicz A, Hopkins WG, Dornowski M, Piernicka M. Exercise Professionals Improve Their Poor Skills in Contracting Pelvic-Floor Muscles: A Randomized Controlled Trial. Res Q Exerc Sport. 2019;90(4):641-50.

67. Pereira LC, Botelho S, Marques J, Adami DB, Alves FK, Palma P, et al. Electromyographic pelvic floor activity: Is there impact during the female life cycle? Neurourol Urodyn. 2016;35(2):230-4.

68. Fitz FF, Paladini LM, Ferreira LA, Gimenez MM, Bortolini MAT, Castro RA. Ability to contract the pelvic floor muscles and association with muscle function in incontinent women. Int Urogynecol J. 2020;31(11):2337-44.

69. Diaz-Alvarez L, Lorenzo-Gallego L, Romay-Barrero H, Prieto-Gomez V, Torres-Lacomba M, Navarro-Brazalez B. Does the Contractile Capability of Pelvic Floor

Muscles Improve with Knowledge Acquisition and Verbal Instructions in Healthy Women? A Systematic Review. Int J Environ Res Public Health. 2022;19(15).

70. Bo K, Stien R. Needle EMG registration of striated urethral wall and pelvic floor muscle activity patterns during cough, Valsalva, abdominal, hip adductor, and gluteal muscle contractions in nulliparous healthy females. Neurourol Urodyn. 1994;13(1):35-41.

71. Smith MD, Russell A, Hodges PW. Do incontinence, breathing difficulties, and gastrointestinal symptoms increase the risk of future back pain? J Pain. 2009;10(8):876-86.

72. Sapsford RR, Hodges PW, Richardson CA, Cooper DH, Markwell SJ, Jull GA. Co-activation of the abdominal and pelvic floor muscles during voluntary exercises. Neurourol Urodyn. 2001;20(1):31-42.

73. Sapsford RR, Richardson CA, Stanton WR. Sitting posture affects pelvic floor muscle activity in parous women: an observational study. Aust J Physiother. 2006;52(3):219-22.

74. Barber MD, Lambers A, Visco AG, Bump RC. Effect of patient position on clinical evaluation of pelvic organ prolapse. Obstet Gynecol. 2000;96(1):18-22.

75. Braverman M, Kamisan Atan I, Turel F, Friedman T, Dietz HP. Does Patient Posture Affect the Ultrasound Evaluation of Pelvic Organ Prolapse? J Ultrasound Med. 2019;38(1):233-8.

76. Rodriguez-Mias NL, Subramaniam N, Friedman T, Shek KL, Dietz HP. Prolapse assessment supine and standing: do we need different cutoffs for "significant prolapse"? Int Urogynecol J. 2018;29(5):685-9.

77. Madill SJ, McLean L. Quantification of abdominal and pelvic floor muscle synergies in response to voluntary pelvic floor muscle contractions. J Electromyogr Kinesiol. 2008;18(6):955-64.

78. Neumann P, Gill V. Pelvic floor and abdominal muscle interaction: EMG activity and intra-abdominal pressure. Int Urogynecol J Pelvic Floor Dysfunct. 2002;13(2):125-32.

79. Bo K, Finckenhagen HB. Is there any difference in measurement of pelvic floor muscle strength in supine and standing position? Acta Obstet Gynecol Scand. 2003;82(12):1120-4.

80. Frawley HC, Galea MP, Phillips BA, Sherburn M, Bo K. Reliability of pelvic floor muscle strength assessment using different test positions and tools. Neurourol Urodyn. 2006;25(3):236-42.

81. Frawley HC, Galea MP, Phillips BA, Sherburn M, Bo K. Effect of test position on pelvic floor muscle assessment. Int Urogynecol J Pelvic Floor Dysfunct. 2006;17(4):365-71.

82. Gimenez MM, Fitz FF, de Azevedo Ferreira L, Bortolini MAT, Lordelo PVS, Castro RA. Pelvic floor muscle function differs between supine and standing positions in

women with stress urinary incontinence: an experimental crossover study. J Physiother. 2022;68(1):51-60.

83. Mastwyk S, McClelland J, Cooper MM, Frawley HC. Pelvic floor muscle function in the standing position in women with pelvic floor dysfunction. Int Urogynecol J. 2021.

84. Morgan DM, Kaur G, Hsu Y, Fenner DE, Guire K, Miller J, et al. Does vaginal closure force differ in the supine and standing positions? Am J Obstet Gynecol. 2005;192(5):1722-8.

85. Kelly M, Tan BK, Thompson J, Carroll S, Follington M, Arndt A, et al. Healthy adults can more easily elevate the pelvic floor in standing than in crook-lying: an experimental study. Aust J Physiother. 2007;53(3):187-91.

86. Dietz HP, Clarke B. The influence of posture on perineal ultrasound imaging parameters. Int Urogynecol J Pelvic Floor Dysfunct. 2001;12(2):104-6.

87. Henriksson L, Ulmsten U, Andersson KE. The effect of changes of posture on the urethral closure pressure in healthy women. Scand J Urol Nephrol. 1977;11(3):201-6.

88. Capson AC, Nashed J, McLean L. The role of lumbopelvic posture in pelvic floor muscle activation in continent women. J Electromyogr Kinesiol. 2011;21(1):166-77.

89. Gilpin SA, Gosling JA, Smith AR, Warrell DW. The pathogenesis of genitourinary prolapse and stress incontinence of urine. A histological and histochemical study. Br J Obstet Gynaecol. 1989;96(1):15-23.

90. Gameiro MO, Miraglia L, Gameiro LF, Padovani CR, Amaro JL. Pelvic floor muscle strength evaluation in different body positions in nulliparous healthy women and its correlation with sexual activity. Int Braz J Urol. 2013;39(6):847-52.

91. Cerruto MA, Vedovi E, Mantovani W, D'Elia C, Artibani W. Effects of ankle position on pelvic floor muscle electromyographic activity in female stress urinary incontinence: preliminary results from a pilot study. Arch Ital Urol Androl. 2012;84(4):184-8.

92. Chen CH, Huang MH, Chen TW, Weng MC, Lee CL, Wang GJ. Relationship between ankle position and pelvic floor muscle activity in female stress urinary incontinence. Urology. 2005;66(2):288-92.

93. Chen HL, Lin YC, Chien WJ, Huang WC, Lin HY, Chen PL. The effect of ankle position on pelvic floor muscle contraction activity in women. J Urol. 2009;181(3):1217-23.

94. Chmielewska D, Stania M, Sobota G, Kwasna K, Blaszczak E, Taradaj J, et al. Impact of different body positions on bioelectrical activity of the pelvic floor muscles in nulliparous continent women. Biomed Res Int. 2015;2015:905897.

95. Halski T, Ptaszkowski K, Slupska L, Dymarek R, Paprocka-Borowicz M. Relationship between lower limb position and pelvic floor muscle surface electromyography activity in menopausal women: a prospective observational study. Clin Interv Aging. 2017;12:75-83.

96. Lee K. Activation of Pelvic Floor Muscle During Ankle Posture Change on the Basis of a Three-Dimensional Motion Analysis System. Med Sci Monit. 2018;24:7223-30.

97. Lee K. Investigation of Electromyographic Activity of Pelvic Floor Muscles in Different Body Positions to Prevent Urinary Incontinence. Med Sci Monit. 2019;25:9357-63.

98. Ptaszkowski K, Paprocka-Borowicz M, Slupska L, Bartnicki J, Dymarek R, Rosinczuk J, et al. Assessment of bioelectrical activity of synergistic muscles during pelvic floor muscles activation in postmenopausal women with and without stress urinary incontinence: a preliminary observational study. Clin Interv Aging. 2015;10:1521-8.

99. Ptaszkowski K, Zdrojowy R, Ptaszkowska L, Bartnicki J, Taradaj J, Paprocka-Borowicz M. Electromyographic evaluation of synergist muscles of the pelvic floor muscle depending on the pelvis setting in menopausal women: A prospective observational study. Gait Posture. 2019;71:170-6.

100. Ptaszkowski K, Zdrojowy R, Slupska L, Bartnicki J, Dembowski J, Halski T, et al. Assessment of bioelectrical activity of pelvic floor muscles depending on the orientation of the pelvis in menopausal women with symptoms of stress urinary incontinence: continued observational study. Eur J Phys Rehabil Med. 2017;53(4):564-74.

101. Halski T, Slupska L, Dymarek R, Bartnicki J, Halska U, Krol A, et al. Evaluation of bioelectrical activity of pelvic floor muscles and synergistic muscles depending on orientation of pelvis in menopausal women with symptoms of stress urinary incontinence: a preliminary observational study. Biomed Res Int. 2014;2014:274938.

102. Sapsford RR, Richardson CA, Maher CF, Hodges PW. Pelvic floor muscle activity in different sitting postures in continent and incontinent women. Arch Phys Med Rehabil. 2008;89(9):1741-7.

103. Nguyen JK, Lind LR, Choe JY, McKindsey F, Sinow R, Bhatia NN. Lumbosacral spine and pelvic inlet changes associated with pelvic organ prolapse. Obstet Gynecol. 2000;95(3):332-6.

104. Kannan P, Winser S, Goonetilleke R, Cheing G. Ankle positions potentially facilitating greater maximal contraction of pelvic floor muscles: a systematic review and meta-analysis. Disabil Rehabil. 2019;41(21):2483-91.

105. Bendix T, Sorensen SS, Klausen K. Lumbar curve, trunk muscles, and line of gravity with different heel heights. Spine (Phila Pa 1976). 1984;9(2):223-7.

106. Russell BS, Muhlenkamp KA, Hoiriis KT, Desimone CM. Measurement of lumbar lordosis in static standing posture with and without high-heeled shoes. J Chiropr Med. 2012;11(3):145-53.

107. Wiedemeijer MM, Otten E. Effects of high heeled shoes on gait. A review. Gait Posture. 2018;61:423-30.

108. El-Shamy F, Moham A. Effect of pelvic postural changes on pelvic floor muscle activity in women with urinary stress incontinence. . Bulletin of Faculty of Physical Therapy. 2013;18:9-14.

109. Keshwani N, McLean L. State of the art review: Intravaginal probes for recording electromyography from the pelvic floor muscles. Neurourol Urodyn. 2015;34(2):104-12.

110. Auchincloss CC, McLean L. The reliability of surface EMG recorded from the pelvic floor muscles. J Neurosci Methods. 2009;182(1):85-96.

111. Keshwani N, McLean L. A differential suction electrode for recording electromyographic activity from the pelvic floor muscles: crosstalk evaluation. Journal of electromyography and kinesiology : official journal of the International Society of Electrophysiological Kinesiology. 2013;23(2):311-8.

112. Okumura K, Yamaguchi K, Tamaki T, Oinuma K, Tomoe H, Akita K. Prospective analyses of female urinary incontinence symptoms following total hip arthroplasty. Int Urogynecol J. 2017;28(4):561-8.

113. Jordre B, Schweinle W. Comparing resisted hip rotation with pelvic floor muscle training in women with stress urinary incontinence: A pilot study. Journal of Women's Health Physical Therapy. 2014;38(2):81-9.

114. Underwood DB, Calteaux TH, Cranston AR, Novotny SA, Hollman JH. Hip and pelvic floor muscle strength in women with and without stress urinary incontinence: A ccase-control study. Journal of Women's Health Physical Therapy. 2012;36(1):55-61.

115. Tuttle LJ, DeLozier ER, Harter KA, Johnson SA, Plotts CN, Swartz JL. The Role of the Obturator Internus Muscle in Pelvic Floor Function. Journal of Women’s Health Physical Therapy. 2016;40(1):15-9.

116. Tuttle LJ, Autry T, Kemp C, Lassaga-Bishop M, Mettenleiter M, Shetter H, et al. Hip exercises improve intravaginal squeeze pressure in older women. Physiother Theory Pract. 2020;36(12):1340-7.

117. Baba T, Homma Y, Takazawa N, Kobayashi H, Matsumoto M, Aritomi K, et al. Is urinary incontinence the hidden secret complications after total hip arthroplasty? Eur J Orthop Surg Traumatol. 2014;24(8):1455-60.

118. Tamaki T, Oinuma K, Shiratsuchi H, Akita K, Iida S. Hip dysfunction-related urinary incontinence: a prospective analysis of 189 female patients undergoing total hip arthroplasty. Int J Urol. 2014;21(7):729-31.

119. Martines GA, Tamanini JTN, Mota G, Barreto ET, Santos JLF, Sartori MGF, et al. Urinary incontinence, overactive bladder, and quality of life in women submitted to total hip replacement. Neurourol Urodyn. 2022;41(3):830-40.

120. Marques SAA, Silveira S, Passaro AC, Haddad JM, Baracat EC, Ferreira EAG. Effect of Pelvic Floor and Hip Muscle Strengthening in the Treatment of Stress Urinary Incontinence: A Randomized Clinical Trial. J Manipulative Physiol Ther. 2020;43(3):247-56.

121. Neumann DA. Kinesiology of the hip: a focus on muscular actions. J Orthop Sports Phys Ther. 2010;40(2):82-94.

122. Agur AMR, Dalley AF. Grant's atlas of anatomy. Edition 14. ed. Philadelphia: Wolters Kluwer; 2017. xviii, 867 pages p.

123. Lee YC, Callary SA, Howie DW, Thewlis D, Solomon LB. The effect of hip position on the length of trochanteric muscles: potential implications for early postoperative management of hip arthroplasty. J Arthroplasty. 2012;27(6):953-60 e1-2.

124. Hartigan E, McAuley JA, Lawrence M, Keafer C, Ball A, Michaud A, et al. Pelvic Floor Muscle Performance, Hip Mobility, and Hip Strength in Women With and Without Self-Reported Stress Urinary Incontinence. The Journal of Women's & Pelvic Health Physical Therapy. 2019;43(4):160-70.

125. Vardi Y, Gruenwald I, Sprecher E, Gertman I, Yartnitsky D. Normative values for female genital sensation. Urology. 2000;56(6):1035-40.

126. North CE, Creighton SM, Smith A. A comparison of genital sensory and motor innervation in women with pelvic organ prolapse and normal controls including a pilot study on the effect of vaginal prolapse surgery on genital sensation: a prospective study. BJOG. 2013;120(2):193-9.

127. Mahoney C, Chok SM, Bryant A, Myers J, Smith A, Reid F. Method of limits: Female genital stretch perception thresholds. Neurourol Urodyn. 2020;39(2):778-84.

128. Mahoney CK, Reid FM, Smith ARB, Myers JE. The impact of pregnancy and childbirth on pelvic sensation: a prospective cohort study. Sci Rep. 2023;13(1):1535.

129. Lowenstein L, Gruenwald I, Itskovitz-Eldor J, Gartman I, Vardi Y. Is there an association between female urinary incontinence and decreased genital sensation? Neurourol Urodyn. 2011;30(7):1291-4.

130. Kharaji G, Nikjooy A, Amiri A, Sanjari MA, Jafari H, Berghmans B, et al. Better Sense of Force Accuracy in Women with Stress Urinary Incontinence Compared with Women Without Stress Urinary Incontinence: A Surprising Result in a Case-Control Study. Middle East Journal of Rehabilitation and Health Studies. 2023;10(1):1-9.

131. Brooks K, McLean L, editors. A novel dynamometry-based method to assess female levator ani muscle proprioception. Abstract 281. International Continence Society 2023 Sept 27-29, 2023; Toronto, Canada. Neurourology and Urodynamics.

132. Kharaji G, Nikjooy A, Amiri A, Sanjari MA. Proprioception in stress urinary incontinence: A narrative review. Med J Islam Repub Iran. 2019;33:60.

133. Smith MD, Coppieters MW, Hodges PW. Is balance different in women with and without stress urinary incontinence? Neurourol Urodyn. 2008;27(1):71-8.

134. Uechi N, Fernandes A, Bo K, de Freitas LM, de la Ossa AMP, Bueno SM, et al. Do women have an accurate perception of their pelvic floor muscle contraction? A cross-sectional study. Neurourol Urodyn. 2020;39(1):361-6.

135. Longo MR, Haggard P. An implicit body representation underlying human position sense. Proc Natl Acad Sci U S A. 2010;107(26):11727-32.

136. Messelink B, Benson T, Berghmans B, Bo K, Corcos J, Fowler C, et al. Standardization of terminology of pelvic floor muscle function and dysfunction: report from the pelvic floor clinical assessment group of the International Continence Society. Neurourol Urodyn. 2005;24(4):374-80.

137. De Luca CJ, Kuznetsov M, Gilmore LD, Roy SH. Inter-electrode spacing of surface EMG sensors: reduction of crosstalk contamination during voluntary contractions. J Biomech. 2012;45(3):555-61.

138. Auchincloss C, McLean L. Does the presence of a vaginal probe alter pelvic floor muscle activation in young, continent women? J Electromyogr Kinesiol. 2012;22(6):1003-9.

139. Koenig I, Luginbuehl H, Radlinger L. Reliability of pelvic floor muscle electromyography tested on healthy women and women with pelvic floor muscle dysfunction. Ann Phys Rehabil Med. 2017;60(6):382-6.

140. Keshwani N, McLean L. Development of a differential suction electrode for improved intravaginal recordings of pelvic floor muscle activity: reliability and motion artifact assessment. Neurourol Urodyn. 2012;31(8):1272-8.

141. Constantinou CE, Omata S. Direction sensitive sensor probe for the evaluation of voluntary and reflex pelvic floor contractions. Neurourol Urodyn. 2007;26(3):386-91.

142. Deindl FM, Vodusek DB, Hesse U, Schussler B. Pelvic floor activity patterns: comparison of nulliparous continent and parous urinary stress incontinent women. A kinesiological EMG study. Br J Urol. 1994;73(4):413-7.

143. Bo K, Frawley HC, Haylen BT, Abramov Y, Almeida FG, Berghmans B, et al. An International Urogynecological Association (IUGA)/International Continence Society (ICS) joint report on the terminology for the conservative and nonpharmacological management of female pelvic floor dysfunction. Neurourol Urodyn. 2017;36(2):221-44.

144. Brink CA, Sampselle CM, Wells TJ, Diokno AC, Gillis GL. A digital test for pelvic muscle strength in older women with urinary incontinence. Nurs Res. 1989;38(4):196-9.

145. Brink CA, Wells TJ, Sampselle CM, Taillie ER, Mayer R. A digital test for pelvic muscle strength in women with urinary incontinence. Nurs Res. 1994;43(6):352-6.

146. Laycock J, Jerwood D. Pelvic floor muscle assessment: The PERFECT Scheme. Physiotherapy. 2001;87(12):631-42.

147. Silva JBD, Sato TO, Rocha APR, Driusso P. "Comparative intra- and inter-rater reliability of maximal voluntary contraction with unidigital and bidigital vaginal palpation and construct validity with Peritron manometer". Neurourol Urodyn. 2020;39(2):721-31.

148. Chiarotto A, Maxwell LJ, Ostelo RW, Boers M, Tugwell P, Terwee CB. Measurement Properties of Visual Analogue Scale, Numeric Rating Scale, and Pain

Severity Subscale of the Brief Pain Inventory in Patients With Low Back Pain: A Systematic Review. J Pain. 2019;20(3):245-63.

149. Ohnhaus EE, Adler R. Methodological problems in the measurement of pain: a comparison between the verbal rating scale and the visual analogue scale. Pain. 1975;1(4):379-84.

150. Ulrich D, Guzman Rojas R, Dietz HP, Mann K, Trutnovsky G. Use of a visual analog scale for evaluation of bother from pelvic organ prolapse. Ultrasound Obstet Gynecol. 2014;43(6):693-7.

151. Trutnovsky G, Guzman-Rojas R, Martin A, Dietz HP. Pelvic floor dysfunction--does menopause duration matter? Maturitas. 2013;76(2):134-8.

Chapter 3

The influence of lumbopelvic posture on the electromyographic activity of the pelvic floor muscles in women with and without stress urinary incontinence

3.1 Abstract

The aims of this study were to determine if pelvic floor muscle (PFM) activation amplitudes differ between women with and without stress urinary incontinence (SUI), to compare PFM activation between the lying and standing positions, and to determine whether changes in lumbopelvic posture (neutral, hyperlordosis, hypolordosis) alter PFM activation. Participants were recruited and stratified into three groups: continent, mild SUI, and moderate SUI. Electromyographic (EMG) signals were recorded from the PFMs at rest and while participants performed maximal effort PFM contractions in standing and lying positions while assuming different lumbopelvic postures. The effect of continence status was determined using the Kruskal-Wallis test and the effect of altered lumbopelvic posture and position on tonic and maximal voluntary PFM activity was examined using Friedman's test. Post-hoc analyses were performed to evaluate pairwise differences. Continent participants (n = 15; age = 29.8 ± 13.7 years) were younger than those with mild (n = 11; age = 46.1 ± 14.4 years) and moderate (n = 13; age = 46.0 ± 10.4 years) SUI. Those with moderate symptoms of SUI generated the lowest maximal PFM activation amplitudes. At the same time, there were no differences in maximal PFM activation amplitudes between continent participants and participants with mild SUI.

Tonic PFM activation did not differ among the groups but was significantly higher in standing than lying for all groups. Maximal PFM EMG activity was lower in standing compared to lying in women with moderate SUI but not in the other groups. Within the SUI cohorts, lying in a hyperlordotic posture resulted in higher tonic activation than neutral lordosis. The highest maximal EMG amplitudes were observed in the continent cohort in a neutral lumbar posture. Standing tonic EMG activation amplitude was lower in the hypolordotic posture than neutral, but only among continent women. Compared to continent women and those with mild SUI, women with moderate SUI symptoms generate lower PFM activation amplitudes during maximum voluntary contraction efforts. While the different lumbopelvic postures influenced PFM activation in women with and without SUI, the effects were inconsistent. In a clinical population, adjustments to lumbopelvic posture may be helpful to facilitate phasic PFM activation or to reduce tonic activation. However, the impact of these adjustments should be evaluated on a case-by-case basis when using postural changes to enhance performance or progress exercises.

3.2 Introduction

Urinary incontinence (UI), or involuntary loss of urine experienced regularly, affects up to half of all women at some point (1, 2). Urine leakage associated with effort or exertion, such as when exercising, coughing, laughing, or sneezing, is referred to as stress urinary incontinence (SUI) and is the most prevalent type of UI among women (2-4). The pelvic floor and its associated muscles, ligaments, and fascia support the pelvic organs and assist with maintaining urinary and fecal continence. Pelvic floor muscle

(PFM) damage or dysfunction has been implicated in SUI (5), although the extent to which PFM dysfunction contributes to SUI is not fully understood (6). There is level 1A evidence (systematic reviews of randomized controlled trials (RCTs) with strong evidence) to support pelvic floor muscle training (PFMT) as a first-line, conservative treatment option for managing SUI (7).

The PFMs are believed to work in synergy with other muscles, particularly those of the trunk and hip (8-12), and may be sensitive to posture and position changes (12-14). Changes in position also impact intra-abdominal pressure (IAP) and the extent of gravitational loading experienced by the PFMs, which might be relevant to PFM activation (15-17). Further, when the load on the pelvic floor is altered by changing lumbopelvic posture, afferent sensory information may be influenced, which could affect PFM activation at rest and during voluntary contraction (15-17). Indeed, measures of PFM function, including displacement of the levator plate, vaginal closure force, PFM strength, endurance, and electromyographic activation, appear to be influenced by body position (15, 18-24). For example, tonic activation of the PFMs (15) and vaginal resting pressure (24) were reported to be higher in standing than lying, more cranial displacement of the pelvic floor was observed in standing than lying (25, 26) when viewed using transabdominal ultrasound, and greater PFM activation with maximal voluntary contractions (MVCs) in lying compared to standing has also been documented (23). Postural adjustments may alter musculoskeletal alignment and could lead to a change in the length of the PFMs, which, in turn, may influence their force-generating capacity.

Functional deficits in PFM performance among women with SUI have been identified, such as lower endurance (27, 28), lower strength (27, 29), slower rate of force production (5), and altered motor control (30, 31). To compensate for diminished performance, some have suggested that women with SUI may use compensatory strategies to maintain continence (10, 28, 30-35). The influence of continence status on PFM activation described using electromyography (EMG) is inconsistent, where observations of higher activation (30, 36), lower activation (31, 33, 35), and no difference in activation (37) have been reported when women with and without SUI are compared. The inconsistencies are likely a result of the heterogeneity of the samples and variations in equipment and study design.

Enhancing or reducing lumbar lordosis is also thought to impact PFM activation (15-18, 21, 36, 38-40). Some authors have reported that PFM activation is higher when PFM MVCs are performed in a posture with reduced lumbar lordosis (16, 17, 40, 41). Others have reported higher PFM activation amplitudes when contraction efforts are performed in a neutral spine position (15) compared to reduced lordosis. Differences in findings may be associated with the experimental approach. In some studies, the desired lumbopelvic position was assumed and maintained actively (15, 18, 36, 40-42), whereas in others, the position was assumed passively (16, 17, 38). Only one study compared women with and without SUI when investigating the effect of altering lumbopelvic posture on PFM activity (36). Sapsford et al. (36) reported higher tonic amplitudes in tall, unsupported sitting compared to slumped sitting in both cohorts. Comparing PFM activation between women with and without SUI as they assume different lumbopelvic positions in lying and standing may improve our understanding of motor control patterns

observed among women with SUI and how they differ from continent women. Performing PFM exercises in positions that facilitate activation may be helpful when teaching women how to perform a more effective PFM contraction, or working on PFM relaxation in positions that lower tonic activation of the PFMs may ultimately result in greater success with PFMT.

The aims of this study were therefore to describe the effect of three lumbopelvic postures (neutral, hyperlordosis, hypolordosis) on tonic and phasic PFM activity in women with and without SUI, to compare PFM activity at rest and during PFM MVCs between the lying and standing positions in women with and without SUI, and finally to compare PFM tonic and maximal activity between women with and without SUI as they assume different lumbopelvic postures.

3.3 Methods

This cross-sectional, observational case-control study was approved by the Queen's University Health Sciences Research Ethics Board (REB#: REH-439-08). All participants provided written informed consent before participating.

3.3.1 Recruitment

Using word of mouth and posters located in the community (physicians' offices, public washrooms, physiotherapy clinics, local gyms, and local hospitals), women between 18 and 70 years of age were recruited to participate. Participants were eligible if they were continent of stool, if they had regularly experienced involuntary leaking of urine with activities such as coughing, laughing, sneezing, and/or exercising over the past

year or if they had not experienced any involuntary urine leakage over the past year. Through a telephone interview conducted by the author, interested potential participants were screened to determine their eligibility. Volunteers were excluded from participating if they had symptoms of urgency urinary incontinence (i.e., a sudden strong urge to urinate leading to leakage), were pregnant, had given birth within the previous 12 months, had undergone gender-affirming surgical procedures, reported abdominal or pelvic surgery in the previous 12 months, or if they experienced low back or lumbopelvic pain that would prevent them from completing the study tasks. An additional inclusion criterion was that, during the functional examination (see Study Protocol section), participants had to perform a correct PFM contraction, defined as the ability to generate a palpable anterior and cranial motion of the PFMs on contraction (43). Obstetric history (parity and delivery mode) was provided through verbal self-report. Participants meeting all the inclusion criteria were invited to attend a 90-minute testing session based in a research laboratory.

3.3.2 Study Protocol

All aspects of the protocol were performed by the author (C. Auchincloss, Physiotherapist) of this dissertation. Upon arrival, participants were asked to empty their bladder (44). Height was measured using a measuring tape secured to the wall and weight was determined using a standard scale. Participants completed three questionnaires: the International Consultation on Incontinence Questionnaire Short Form (ICIQ-UI SF) (45), the Incontinence Impact Questionnaire-7 (IIQ-7) (46), and the Urogenital Distress

Inventory-6 (UDI-6) (46). Information from all three questionnaires was used to exclude participants whose symptoms were consistent with urgency UI or mixed UI. Those who scored 0 on the ICIQ-UI SF were considered continent. Those who scored a 1 or higher on the ICIQ-UI SF and indicated urine leakage on activities such as coughing, laughing, sneezing, and physical activity were classified as SUI. The ICIQ-UI SF is a robust questionnaire that has demonstrated good construct validity and moderate to very good test re-test reliability (Cronbach's alpha of 0.95) (45). Participants with SUI were later stratified into cohorts according to incontinence severity; those who scored from 1 to 5 on the ICIQ-UI SF were considered to have mild SUI, those scoring between 6 and 12 were considered to have moderate SUI, and those who scored more than 12 were considered to have severe SUI (47).

The researcher, who is an experienced pelvic health physiotherapist and had > 10 years of experience in the assessment and management of pelvic floor dysfunction, performed a pelvic examination. Participants assumed a supine position on an examination table and flexed their knees to have their feet supported on the examination table. The researcher inserted her gloved and lubricated index finger into the vagina and palpated the PFMs at the 8 o'clock and 4 o'clock positions of the perineal clock. Strength was scored between 0 and 5 on each side using the Modified Oxford Scale (MOS) (48). PFM tone was assessed at the same locations while participants were instructed to breathe quietly and relax their PFMs. Muscle tone was rated between -3 (low tone) and +3 (high tone), while 0 represented normal PFM tone, based on the seven-point scale developed by Reissing et al. (49). The strength and tone scores recorded from the right and left sides were averaged for analysis. Participants deemed unable to perform a PFM contraction

(MOS = 0) after verbal instruction and basic tactile facilitation techniques were excluded (n = 1).

3.3.3 Instrumentation

Electromyographic data from the PFMs were recorded using a modified version of the differential suction electrode (DSE) described by Keshwani and McLean (Figure 3.1) (50). The modification involved recessing the electrodes and filling the electrode recesses with conductive gel to minimize motion artifact. The DSE was inserted into the vagina and adhered to the vaginal wall on one side at the level of the PFMs. As described by Keshwani and McLean (50), it was positioned over the PFMs on the side that was determined through manual palpation to have greater PFM bulk, or on the right side if there was no difference in muscle bulk. Although it has been recommended that EMG be recorded separately for each side of the pelvic floor (51), there is evidence that the activation pattern across the different positions is consistent between the left and right sides, even though the activation amplitudes may not be (52). After proper skin preparation, a surface Ag-AgCl reference electrode (20mm X 25mm, HH5000 EKG, Harris Healthcare, Massachusetts) was adhered to the anterior superior iliac spine ipsilateral to the side where the DSE was located. The electrodes were interfaced with Delsys Bagnoli™ 16-channel EMG amplifiers via Delsys™ D.E.2.1 pre-amplifiers (bandwidth 20-450 Hz ±10%, CMRR 92dB (typical), at 60Hz, input resistance>$10^{15}\Omega$, and overall noise of <1.2μV (RMS)) using an overall gain of X1000. EMG data were sampled at 1000 Hz using Delsys^{TM} EMGWorks Acquisition software, converted to digital form through a 16-bit National Instruments A/D converter (PCI-MCIA-EIC), and stored on a personal computer for offline analysis.

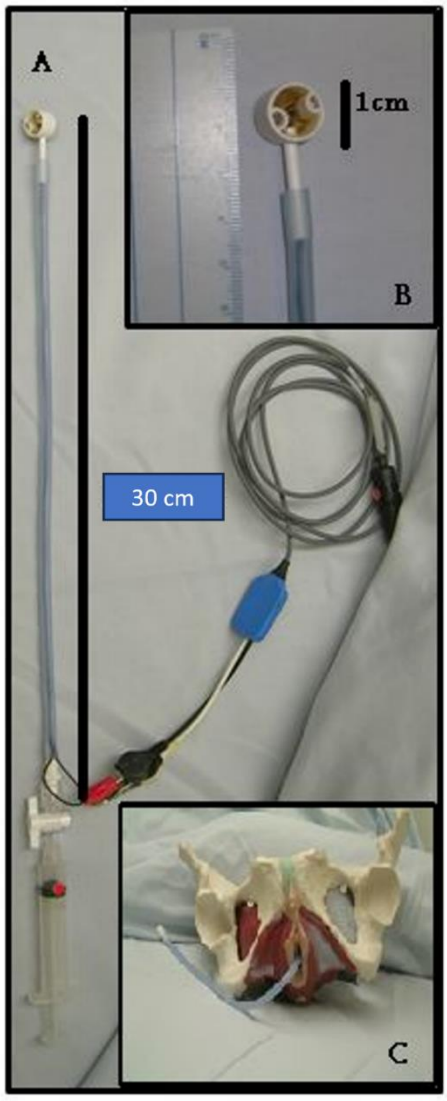

Figure 3.1 Differential Suction Electrode (DSE)

A. DSE interfaced with a modified Delsys D.E.2.1 pre-amplifier and lead. B. Detection surface that is adhered to the vagina wall using suction force. Note bilateral semicircular compartments where the detection surfaces are recessed. C. External view of the perineum once the DSE was attached to one side of the vaginal wall at the level of the PFMs.

3.3.4 Tasks

Tonic and maximal PFM activity was recorded with participants lying and standing while they assumed different positions that altered lumbopelvic posture; the order of the positions was randomized using the "random sort" function in Excel. Tonic PFM activity was recorded for 10-seconds in each position after participants were instructed to relax their PFMs as much as possible. Maximal activity was recorded during PFM MVCs, where participants were asked to contract their PFMs by pulling their perineum upward and squeezing inward around their vagina and anus as hard as possible. Three repetitions of each task were performed while EMG data were recorded over a 10-second window. Participants were given a minimum of one minute of rest between repetitions.

3.3.5 Positions

Three positions were assumed both in lying as well as in standing (Figure 3.2). In lying, i) a *neutral* lumbopelvic posture was assumed where participants were lying on their back with their hips and knees flexed to 60° and their feet flat on the table (crook-lying position), ii) a *hyperlordosis* posture was assumed where participants were lying on their back with their hips and knees fully extended (supine position), and iii) a *hypolordosis* posture was assumed where participants were lying on their back with their hips and knees flexed to 90° and supported by an adjustable height stool (tabletop position). Lumbopelvic posture was altered in standing by rotating the pelvis; i) a *neutral* lumbopelvic posture was assumed where participants assumed their usual standing posture, ii) a *hyperlordosis* posture was assumed where participants tilted their pelvis anteriorly to increase their lumbar lordosis, and iii) a *hypolordosis* posture was assumed

where participants posteriorly rotated their pelvis to decrease their lumbar lordosis. To ensure that participants remained in the desired lumbopelvic posture across tasks and trials in standing, they were positioned close to a wall and instructed not to lean on the wall. To maintain the hyperlordotic posture, participants tilted their pelvis anteriorly and made gentle contact with the wall at their mid-sacrum and mid-thoracic spine. To maintain the hypolordotic position, participants made gentle contact with the wall at their lumbosacral junction. Participants remained in the desired test position while all data associated with the position were recorded, visual inspection was used to monitor consistency within the positions during data collection. Trials were repeated if the participant moved out of position during the recording period.

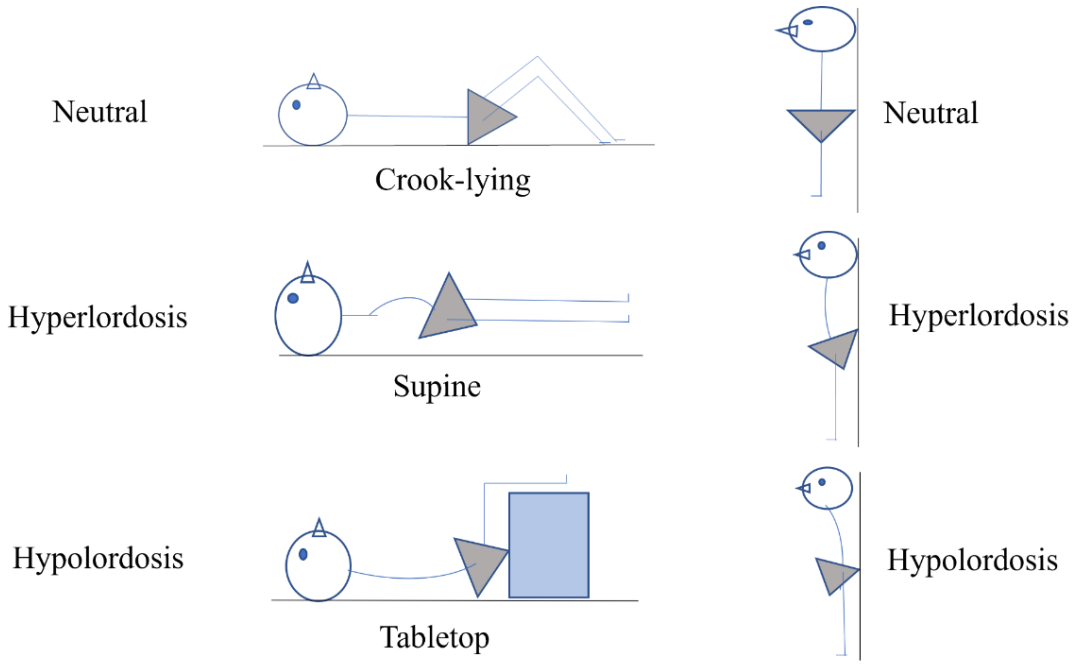

Figure 3.2 Lying and standing positions where lumbopelvic posture was altered

3.3.6 Data Reduction

Data reduction was performed using Delsys™ EMGWorks Analysis software version 4.0. All EMG data files were high pass filtered using a 5th-order Butterworth filter (cut-off 20Hz) to remove any influence of motion artifact. Files were then low pass filtered using a 400ms sliding RMS window. Tonic PFM activity was defined as the mean RMS amplitude computed between the 2nd and 4th second of each data file. Maximal PFM activity, equivalent to the maximum sustained activation amplitude, was calculated using the mean RMS amplitude computed over two seconds while the contraction was sustained, centered about the peak of the smoothed data file.

3.3.7 Statistical Analysis

Data analysis was performed using IBM SPSS Statistics 25 and Minitab 18. The distribution of all demographic and outcome variables was assessed using the Ryan Joiner test in Minitab 18. All continuous demographic data were normally distributed; therefore, between-group differences were tested using one-way analyses of variance, where Tukey's post-hoc analysis was used to determine pairwise differences. Group differences in EMG data (as well as PFM strength and tone) were analyzed using the Kruskal-Wallis test, with the Mann-Whitney U test used to determine pairwise differences between groups and postures in the EMG data.

The effect of posture on tonic and maximal PFM EMG activity was determined for each group independently using Friedman’s two-way analysis of variance by ranks test. Where significant posture effects were found, the Wilcoxon Signed-Rank test was used to examine pairwise differences in PFM activity and to examine differences in PFM activity between lying and standing. To compute effect sizes from non-parametric data,

the test statistic was divided by the square root of the number samples, reported as an *r*-value, and described using the following interpretation (no effect, r <0.10; small effect, 0.10<r<0.23; moderate effect, 0.24 <r<0.36; large effect, r ≥ 0.37) (53). Alpha (α = 0.05) was adjusted to account for multiple comparisons using the Bonferroni correction method. Findings were described as trends when *p*-values were equal to or less than double the adjusted alpha.

3.4 Results

3.4.1 Participant demographics

Forty-five participants were deemed eligible after the telephone screening. Six of the 45 participants were considered ineligible during the testing session: one was unable to contract their PFMs, two experienced discomfort during the assessment that was unexpected and precluded them from participating (they were subsequently referred to their physician for further examination), and three indicated they had symptoms of urgency incontinence on the written questionnaires even though they had denied symptoms consistent with urgency urinary incontinence during the telephone screening (Figure 3.3). A complete description of demographic data from the 39 participants who remained is displayed in Table 3.1. Continent participants were significantly younger than those with SUI ($p = 0.002$), had lower BMI than those with moderate SUI ($p = 0.008$), and had lower parity compared to both groups with incontinence ($p < 0.003$). Manually assessed PFM strength and tone were not significantly different among the groups (Table 3.1). Scores on the questionnaires (IIQ-7, UDI-6, and ICIQ-UI-SF) were

significantly different among the groups, such that continent participants scored the lowest and those with moderate SUI scored the highest ($p < 0.017$).

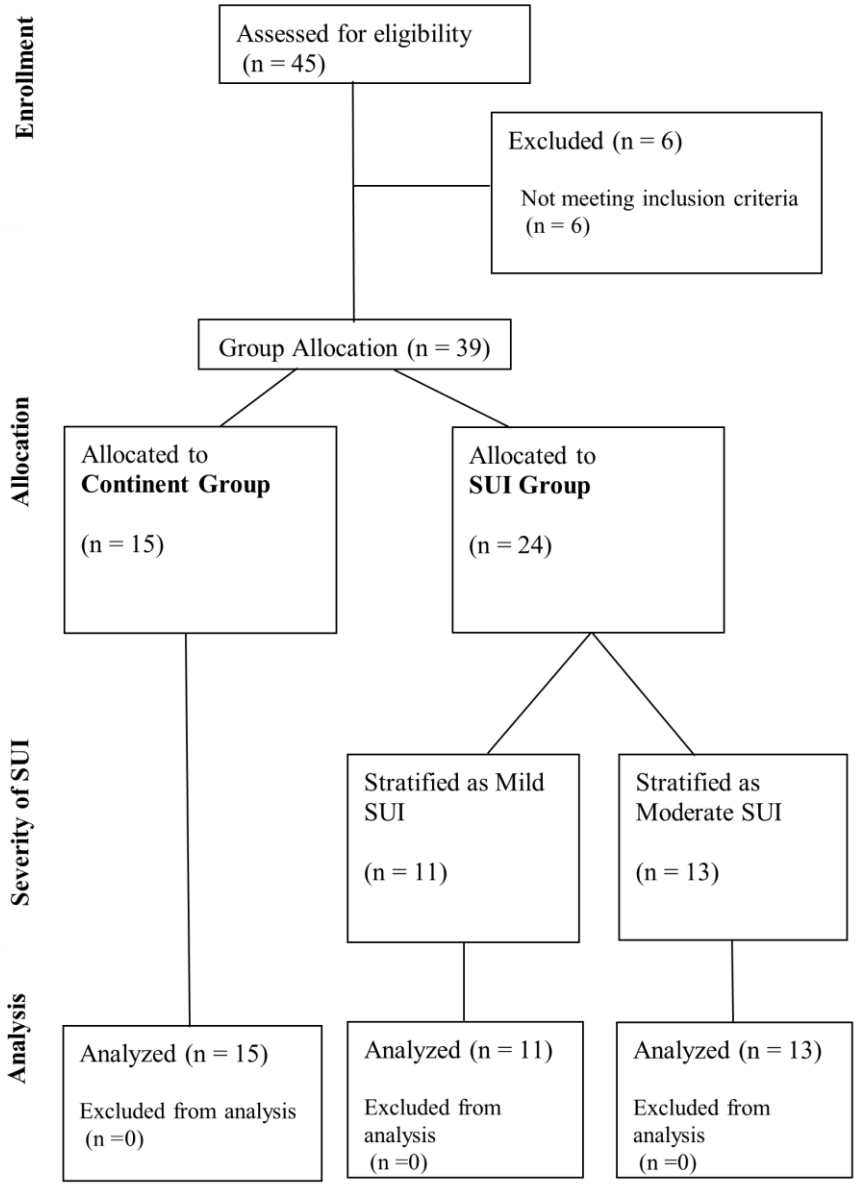

Figure 3.3 Participant flowchart

Stress urinary incontinence (SUI)

Table 3.1 Demographic data displayed by continence status

Groups	Continent (n = 15)	Mild SUI (n = 11)	Moderate SUI (n = 13)	
	Mean(SD)	*Mean(SD)*	*Mean(SD)*	*Group Effect*
Age (years)	29.8(13.5)[a]	46.1(14.4)[b]	46.0(10.4)[b]	***F*=7.428, *p*=0.002***
BMI (kg/m^2)	22.9(3.1)[a]	24.7(3.0)	28.8(6.8)[b]	***F*=5.574, *p*=0.008***
IIQ-7 (0-100)	0(0)[a]	7.0(8.3)[b]	27.6(10.9)[c]	***F*=45.267, *p*<0.001***
UDI-6 (0-100)	0(0)[a]	16.0(10.5)[b]	35.1(15.4)[c]	***F*=27.541, *p*<0.001***
ICIQ-UI SF (0-21)	0(0)[a]	4.2(0.8)[b]	9.1(4.0)[c]	***F*=41.609, *p*<0.001***
	Median(IQR)	*Median(IQR)*	*Median(IQR)*	*Group Effect*
Parity (n)	0.0(0.3)[a]	2.0(2.0)[b]	2.0(1.5)[b]	***H*=11.60, *p*=0.003***
PFM Tone (-3-+3)	0.5(1.0)	0.5(1.3)	0.0(1.6)	*H*=2.07, *p*=0.355
PFM Strength (0-5)	4.0(1.0)	4.0(1.0)	4.0(1.3)	*H*=2.81, *p*=0.245

SUI (stress urinary incontinence), SD (standard deviation), IQR (interquartile range), BMI (body mass index), IIQ-7 (Incontinence Impact Questionnaire-7), UDI-6 (Urogenital Distress Inventory-6), ICIQ-UI SF (International Consultation on Incontinence Questionnaire Short Form), PFM (pelvic floor muscle). '*' indicates where significant differences were detected. Significant pairwise differences ($\alpha \leq 0.017$) are indicated using alphabetical superscripts.

3.4.2 PFM activation in women with and without stress urinary incontinence

While assuming the lumbopelvic postures, no significant differences were detected in the amplitude of tonic PFM activity between the continent women and women with SUI (Table 3.2). However, group differences were detected in the amplitude of maximal PFM activity across all the test positions in lying and standing with a somewhat consistent pattern (Table 3.3). Maximal PFM activity was higher in continent participants and participants with mild SUI compared to participants with moderate SUI in most postures (Table 3.3), where the effect size was moderate to large (r = 0.35 to 0.85). Maximal PFM activity was not significantly different between continent participants and those with mild SUI in any postures ($p > 0.05$).

Table 3.2 The effect of continence status and posture on PFM activation

	Continent (n = 15)	Mild SUI (n = 11)	Mod SUI (n = 13)	***Group Effect***
Lying Postures				
Neutral				
Median (IQR) (uV)	2.93 (2.93)	1.73 (2.51)‡	1.79 (2.47)[a]	$H = 0.490$, $p = 0.782$
Hyperlordosis				
Median (IQR) (uV)	3.48 (3.80)	2.77 (1.85)‡	3.04 (3.30)[b]	$H = 0.050$, $p = 0.976$
Hypolordosis				
Median (IQR) (uV)	2.04 (1.56)	2.56 (1.31)	2.51 (2.03)	$H = 0.840$, $p = 0.656$
Posture Effect	$\chi^2 = 1.389$, $p = 0.499$	**$\chi^2 = 7.000$, $p = 0.030$**	**$\chi^2 = 13.067$, $p = 0.001$**	
Standing Postures				
Neutral				
Median (IQR) (uV)	10.25 (7.97)[a]	10.24 (10.17)	6.88 (5.28)	$H = 4.470$, $p = 0.107$
Hyperlordosis				
Median (IQR) (uV)	9.13 (6.52)	8.12 (8.78)	7.68 (6.01)	$H = 1.320$, $p = 0.517$
Hypolordosis				
Median (IQR) (uV)	7.79 (9.87)[b]	11.54 (10.87)	6.19 (5.52)	$H = 4.590$, $p = 0.101$
Posture Effect	**$\chi^2 = 12.359$, $p = 0.002$**	$\chi^2 = 1.000$, $p = 0.607$	$\chi^2 = 3.378$, $p = 0.185$	

PFM pelvic floor muscle; SUI stress urinary incontinence; Mod SUI group with moderate symptoms; IQR interquartile range; *uV* microvolts. Significant pairwise differences ($\alpha \leq 0.017$) are indicated using alphabetical superscripts and trends are indicated using ‡.

Table 3.3 The effect of continence status and posture on PFM maximal activation

					Pairwise Differences		
Lying Positions	**Continent** (n = 15)	**Mild SUI** (n = 11)	**Mod SUI** (n = 13)	*Group Effect* *α = 0.05*	*Pairs*	*p- value* *α = 0.017*	*Effect size (r)*
Neutral							
Median (IQR) (uV)	38.28 (23.85)	37.42 (27.43)	29.50 (5.78)	***H* = 21.57, *p* < 0.001**	Cont Mild	*p* = 0.654	*r* = 0.05
					Cont Mod	***p* < 0.001**	***r* = 0.44**
					Mild Mod	***p* < 0.001**	***r* = 0.48**
Hyperlordosis							
Median (IQR) (uV)	37.49 (20.65)	41.79 (37.20)	28.46 (16.73)	***H* = 12.78, *p* = 0.002**	Cont Mild	*p* = 0.387	*r* = 0.10
					Cont Mod	***p* = 0.002**	***r* = 0.35**
					Mild Mod	***p* = 0.004**	***r* = 0.34**
Hypolordosis							
Median (IQR) (uV)	35.82 (21.37)	42.79 (28.27)	29.00 (16.08)	***H* = 7.09, *p* = 0.029**	Cont Mild	*p* = 0.407	*r* = 0.11
					Cont Mod	*p* = 0.057	*r* = 0.23
					Mild Mod	***p* = 0.011**	***r* = 0.35**
Posture Effect	**χ^2 =14.389**	χ^2 = 1.083	χ^2 = 1.800				
α = 0.05	***p* < 0.001**	*p* = 0.582	*p* = 0.407				
Standing Positions							
Neutral							
Median (IQR) (uV)	40.13 (17.02)	39.66 (26.67)	23.33 (13.45)	***H* = 34.48, *p* < 0.001**	Cont Mild	*p* = 0.406	*r* = 0.09
Mean rank	81.9	73.4	38.3		Cont Mod	***p* < 0.001**	***r* = 0.85**
					Mild Mod	***p* < 0.001**	***r* = 0.84**
Hyperlordosis							
Median (IQR) (uV)	38.96 (21.99)	35.40 (24.33)	25.44 (15.64)	***H* = 36.30, *p* < 0.001**	Cont Mild	*p* = 0.059	*r* = 0.21
Mean rank	85.5	69.7	38.6		Cont Mod	***p* < 0.001**	***r* = 0.65**
					Mild Mod	***p* < 0.001**	***r* = 0.42**
Hypolordosis							
Median (IQR) (uV)	37.59 (15.44)	33.48 (26.31)	23.99 (13.53)	***H* = 32.23, *p* < 0.001**	Cont Mild	*p* = 0.126	*r* = 0.17
Mean rank	84.3	69.2	40.1		Cont Mod	***p* < 0.001**	***r* = 0.64**
					Mild Mod	***p* = 0.001**	***r* = 0.37**
Posture Effect	χ^2 =5.538	χ^2 =3.000	χ^2 =2.533				
α = 0.05	*p* = 0.063	*p* = 0.223	*p* = 0.282				

PFM pelvic floor muscle; SUI stress urinary incontinence; IQR interquartile range; uV microvolts; Cont group without SUI; Mild group with mild SUI; Mod group with moderate symptoms.

3.4.3 The influence of body position and posture on PFM activation

PFM activation in the lying and standing positions

Tonic PFM activation was higher in standing than lying among all three groups (Table 3.4). The effect size was moderate in the continent group ($r = 0.35$) and large in the groups with mild ($r = 0.64$) and moderate ($r = 0.51$) SUI. Participants with moderate SUI generated higher PFM maximum voluntary activation amplitudes when lying compared to standing ($z = -3.391$, $p = 0.001$), with a large effect size ($r = 0.46$), while those with mild SUI and continent participants did not.

The effect of lumbopelvic posture on PFM activation

Tonic PFM activation was influenced by altered lumbopelvic posture in continent participants while standing, but in participants with SUI, altered lumbopelvic posture only affected tonic activation when lying (Table 3.2). Continent participants generated higher tonic PFM activation in the neutral stance compared to the hypolordotic stance, and the effect size was large ($r = 0.41$). In contrast, higher tonic PFM activity was observed while lying in the hyperlordotic posture compared to lying in a neutral position in both SUI groups. The effect was significant among participants with moderate SUI ($p = 0.001$) but could only be considered a trend among participants with mild SUI ($p = 0.030$). In addition, and only in participants with moderate SUI, tonic PFM activation while lying in the hyperlordotic posture was higher than in the hypolordotic posture.

Maximal PFM activity was affected by altering lumbopelvic posture in continent participants, but only while lying, where higher EMG amplitudes were recorded when participants assumed the neutral and hyperlordosis postures compared to when they

adopted the hypolordosis posture (Table 3.3). Maximal PFM activity was not influenced by a change in lumbopelvic posture in participants with SUI.

Table 3.4 The effect of altering body position on PFM activation

	Continent (n = 15)	**Mild SUI** (n = 11)	**Moderate SUI** (n = 13)
Lying vs Standing (Tonic)	**z = -4.256, *p*<0.001***	**z = - 4.994, *p*<0.001***	**z = -5.121, *p*<0.001***
Lying vs Standing (Maximal)	z=-641, *p*=0.522	z=0.000, *p*=1.000	**z = -3.391, *p*=0.001***

PFM (pelvic floor muscle). SUI (stress urinary incontinence). The test statistic and associated p-value are reported, with * indicating a significant posture effect.

3.5 Discussion

Through this study, we found that tonic PFM activation amplitude is not different between women with and without SUI regardless of posture or position, and that it is significantly higher when standing compared to lying for all groups. Of the three cohorts, participants with moderate symptoms of SUI generated the lowest maximal voluntary PFM activation amplitudes, and participants with mild SUI and no SUI had comparable PFM activation amplitudes. Altering lumbopelvic posture influenced tonic and maximal PFM activation amplitudes, yet the effect was different within each cohort. Further, PFM activation amplitudes (both tonic and maximal) were affected by position differently based on the severity of SUI symptoms.

The effect of continence status and severity on PFM activity

While a large body of literature describes PFM performance and activation patterns in women with SUI (5, 10, 28, 33), few have presented results with SUI cohorts

divided by symptom severity (24, 30, 31). Conservative management of SUI using exercise and behavioural therapy techniques tend to have higher success rates in women with mild SUI than in those with more severe symptoms (30, 54, 55). The results of this study suggest that maximal PFM activation characteristics are different between those with mild and moderate SUI. Women with moderate SUI generated lower activation amplitudes than those with mild SUI and they were the only cohort that generated lower maximum activation amplitudes in standing compared to lying. Similarly, in a group of 57 women with pelvic floor dysfunction, Mastwyk et al. (24) reported that participants with greater severity of symptoms generated lower vaginal squeeze pressures in lying and standing positions. My research team members and I suspect that relative to women with mild SUI symptoms, those with moderate to severe symptoms may have sustained more extensive damage to the pelvic muscles, nerves, and/or connective tissues, which may impact sensorimotor control and result in lower activation amplitudes in positions where the PFMs are challenged. Based on the findings of this study, women with moderate to severe SUI symptoms may benefit from assuming a supine position during initial exercise training sessions. PFM exercises may then be progressed by moving toward upright positions.

Despite mounting evidence that symptom severity can influence response to conservative treatment (54, 55) and may influence PFM performance (24, 30, 31), national guidelines do not typically include symptoms severity in baseline assessment (56). A complete evaluation should always include a measure of symptom severity, either using a questionnaire recommended by the International Continence Society (57) or a standardized pad test (58).

The effect of posture and position on PFM activation

Moving from lying to standing introduces a shift in gravitational forces that influences loading on the PFMs. Gravity is thought to influence aspects of PFM performance, such as force generation, PFM displacement, endurance, and PFM activation (19, 22, 23, 25). The higher tonic PFM activation observed when participants moved from lying to standing positions was not surprising; similar results have been reported previously in women who were continent (15) and in women with SUI (23). The PFMs have a high density of type I muscle fibers (59, 60), making them suited to postural tasks. In standing, they contribute to supporting the weight of the pelvic and abdominal organs, and thus, it makes sense to see higher tonic activation amplitudes in standing compared to lying. Consistent with our EMG findings, vaginal resting pressure has been reported to be higher standing than lying (19, 22-24). The challenge with interpreting resting vaginal pressures is accepting that total vaginal resting pressure is the sum of the intra-abdominal pressure and the pressures generated by the supporting action of the PFMs.

The PFMs will have to overcome gravity and the weight of the abdomino-pelvic viscera when contracting in upright positions, presumably increasing the load. When participants performed maximal effort contractions, maximal EMG activation was lower in standing than lying, but only among participants with moderate SUI. Gimenez et al. (23) observed lower EMG activation amplitudes, lower vaginal squeeze pressure, and poorer PFM performance determined using digital palpation in standing compared to lying in a large group (n=101) of women with SUI. Mastwyk et al. (24) also suggested

that PFM function differs in standing compared to lying in symptomatic women, where strength measured using digital palpation was lower while standing even though vaginal squeeze pressure measured using manometry was higher. Together, these findings reflect some degree of sensorimotor deficit, compromised motor control, or loss of endopelvic fascia integrity, and these seem to be more prevalent among women with more severe SUI symptoms, especially in gravity-dependent upright positions. Interestingly, in a group of patients who had completed a PFMT program, Bo and Finkenhagen (22) concluded that PFM strength, measured in supine using a balloon catheter connected to a fiberoptic pressure transducer, accurately reflected strength measured in standing.

The effect of lumbopelvic posture on tonic PFM activity was dependent on body position (upright versus lying), continence status, and severity of symptoms. In regular standing, the pelvic inclination is such that the load from the abdominal and pelvic viscera is partially supported by the pubic bones and lower anterior abdominal wall (61) and partially supported by the pelvic floor. When lumbar lordosis is increased with pelvic anteversion, the load on the anterior portion of the pelvic diaphragm from the pelvic viscera may decrease as the bony pelvis and anterior abdominal wall assume the weight. In comparison, when lumbar lordosis is reduced by adopting a posterior pelvic tilt, there may be less load borne by the bony pelvis and abdominal muscles such that the PFMs must support more of the load. Because the abdominal muscles are activated to maintain the posterior pelvic tilt position, further pelvic floor loading may occur as intra-abdominal pressure is generated (12). Thompson et al. (10) and Madill et al. (30) reported differences in the synergies between abdominal and PFM activation among women with mild, moderate to severe, and no SUI. Because tonic and maximal PFM activity may be

influenced by changes in intra-abdominal pressure, maladaptive synergies between the abdominal and PFMs could contribute to the different activation amplitudes observed.

We expected that when standing in a hypolordotic posture, tonic and maximum PFM activity would be higher than in the neutral and hyperlordotic position, to meet the increase in demand placed on the pelvic floor in this position. However, our findings demonstrated that tonic activity was lower in hypolordosis than in neutral (continent group) and maximum PFM activity was not affected by lumbopelvic posture. Other studies have reported a similar impact of postural change on tonic PFM activation in standing (16, 38, 42, 62) as well as when seated (18, 36), and may be attributed to the type of electrode used to acquire the EMG data, although we cannot be certain. Our maximal activation results were consistent with what was reported by Halski et al. (42) in a small (n=16) cohort of post-menopausal women, but in contrast to results found by Capson et al. (15) and Ptaszkowski et al. (40). Using single-use vaginal probes with large detection surfaces mounted on the sides, both Capson et al. (15) and Ptaszkowski et al. (40) observed higher maximal PFM activity when the hypolordosis posture was assumed compared to assuming either a neutral or hyperlordosis posture. Larger detection surfaces will likely capture global muscle activation, whereas smaller detection surfaces will likely represent focal activation. The DSE electrode used in this research captures activation from a small moto-neuron pool where crosstalk contamination is minimized (50, 63).

In contrast to the standing position, the effect of gravitational load was removed by having participants lie on their backs before adjusting the position of their lower limbs to achieve the desired lumbopelvic postures. Although there was no effect of lumbopelvic

posture on tonic PFM activity in women without SUI, a significant position effect among participants in the SUI cohorts was detected, where tonic activity was highest in the hyperlordotic posture. One other study used this method to achieve different lumbopelvic postures to examine the effect of posture on tonic PFM activation (64). Unlike our findings, Halski et al. (64) reported that compared to the neutral and hypolordotic positions, tonic PFM activity was lower when participants were in the hyperlordotic position. Participants in the Halski et al. (64) study were post-menopausal women of unknown continence status (n=55), and they computed tonic PFM activation amplitude from EMG data that were recorded during the five-second rest intervals between maximal effort PFM contractions; it is unknown if participants returned to their actual baseline amplitude between contractions.

Maximal PFM activation was only influenced by change in lumbopelvic posture in the continent group and only in the lying position. My collaborators and I observed the lowest maximal PFM activation in the hypolordosis posture. When lying in the tabletop pose with all of the limbs supported, lumbar lordosis is reduced with the sacrum in counternutation (65), and there is less myofascial tension across the abdominal and hip flexor muscles (66). Although we cannot be certain, we hypothesize that in this position the levator ani portion of the PFMs may be shortened and outside of their optimal length to operate.

Altered muscle length across the PFMs and potential change in proprioceptive feedback from the PFMs in this position may contribute to the lower activation amplitudes observed. These results are consistent with Halski et al. (64). It is unclear why a similar effect was not observed in symptomatic women, but this could again be related

to reduced proprioceptive input; more significant changes in posture may be needed to impact activation amplitudes among women with moderate SUI.

Differences in participant characteristics, study protocols, and/or recording devices may explain inconsistencies in study findings. Most notable is the configuration, size, and shape of the EMG recording devices (51, 67, 68). The DSE used to record PFM EMG in this study is more specific and less influenced by crosstalk and motion artifact than the large EMG electrodes mounted on intravaginal probes used in other studies (50, 51, 63). The DSE has small, recessed recording areas that are sized and spaced appropriately for the PFMs and are, therefore, less likely to pick up crosstalk from neighbouring muscles (63). Crosstalk contamination may be particularly relevant in women who use substitution strategies such as bracing or who activate other nearby muscles (e.g., gluteals, hip adductors, and abdominals) when they contract their PFMs. Because the DSE is attached to the vaginal wall using a suction mechanism, there is less opportunity for electrode movement within the vagina compared to large probes with smooth surfaces. Indeed, vaginal sensors can move within the vagina during position changes and even during a PFM contraction, impacting amplitude characteristics of the EMG signal as they are more prone to recording crosstalk and motion artifact (51). While removing the DSE from the vaginal wall of all participants, the examiner confirmed that the electrode stayed in place throughout the experiment.

While tonic PFM activation amplitude has been reported to be influenced by bladder fullness (33, 44, 69), which may have affected the results of other studies, it is unlikely that the state of bladder filling influenced the results of the present study. All participants were required to empty their bladder just before data collection, and the order

of the positions was randomized. The lack of modulation of tonic PFM activation with changes in standing lumbopelvic posture observed in the cohort with SUI may also be explained by an inherent sense of vulnerability to leakage in a standing position: participants with SUI may consciously or unconsciously activate their PFMs, masking any more subtle effects related to changes in posture.

It is essential to remember that electromyographic data reflect the electrical activation of the muscle where higher amplitudes indicate greater excitation of the motoneuron pool. Although muscle activation can provide information about muscle excitability, it does not directly represent force production or strength. Therefore, results from studies using EMG and those using vaginal closure force, vaginal pressure, or manual muscle testing as an indication of strength may differ.

Limitations

The groups in the present study were not matched by age or parity. Given that these are both known risk factors for the development of SUI, these demographic differences among study groups are not surprising based on the recruitment strategies used, but they may have influenced the findings. Upon stratifying participants by the severity of incontinence, the groups with SUI included those with mostly mild (ICIQ 1-5) and moderate SUI (ICIQ = 6 - 12); only one participant fit the criteria for severe SUI; thus, this participant was grouped with those who reported moderate symptoms. The participants with mild and moderate SUI had similar demographic features, yet only those with moderate SUI had lower PFM activation amplitudes than the continent participants.

Therefore, the extent to which demographic characteristics may have influenced the findings is yet to be determined.

The lumbopelvic postures assumed in the current study were not quantitatively measured. Still, they were stringently monitored through visual inspection by the researcher, and participants were required to maintain each test position throughout each repetition using specific landmark cues. The wall was used as support to minimize postural sway and muscle activation. EMG activation of the abdominal muscles was not recorded. Recording EMG from the abdominal muscles may have provided valuable information to interpret the results, particularly the differences in tonic activation seen in the participants with mild SUI but not in those with moderate SUI. As is evident in Table 3.1, the participants in our sample had relatively high BMIs. Surface EMG can be particularly problematic when there is excess fatty tissue between the muscles and the skin surface, as landmarking is difficult and crosstalk is unavoidable. Fine-wire electrodes would be required to record concurrent abdominal muscle activation appropriately.

It remains unknown what magnitude of change in EMG activation amplitude is required to induce clinically meaningful differences in PFM force generation or, more importantly, urethral pressure in the case of SUI.

Conclusions

The findings of this study show that, across different lumbopelvic postures, maximal PFM activity is dependent on the presence and severity of SUI, whereas tonic PFM activity is not. As expected, tonic PFM activity was higher in standing than supine

for all participants. Both tonic and phasic PFM activity were affected by altering lumbopelvic postures, but the effect was dependent on continence status. These findings reinforce the importance of stratifying women with SUI symptoms based on the severity of symptoms for research. The differences in PFM EMG activation induced by changes in lumbopelvic posture deserve further consideration. Our results demonstrate that the effects of changing lumbopelvic posture by assuming different positions cannot be generalized across women with or without SUI presenting at a clinic or participating in individual or group exercise settings. Individual assessment of the pelvic floor, including the responsiveness of the PFMs to postures and position changes, may be helpful when prescribing exercises, particularly in teaching PFM contractions or progressing exercise difficulty.

3.6 References

1. Abufaraj M, Xu T, Cao C, Siyam A, Isleem U, Massad A, et al. Prevalence and trends in urinary incontinence among women in the United States, 2005-2018. Am J Obstet Gynecol. 2021;225(2):166 e1- e12.

2. Milsom I, Gyhagen M. The prevalence of urinary incontinence. Climacteric. 2019;22(3):217-22.

3. Haylen BT, de Ridder D, Freeman RM, Swift SE, Berghmans B, Lee J, et al. An International Urogynecological Association (IUGA)/International Continence Society (ICS) joint report on the terminology for female pelvic floor dysfunction. Neurourol Urodyn. 2010;29(1):4-20.

4. Minassian VA, Stewart WF, Wood GC. Urinary incontinence in women: variation in prevalence estimates and risk factors. Obstet Gynecol. 2008;111(2 Pt 1):324-31.

5. Morin M, Bourbonnais D, Gravel D, Dumoulin C, Lemieux MC. Pelvic floor muscle function in continent and stress urinary incontinent women using dynamometric measurements. Neurourol Urodyn. 2004;23(7):668-74.

6. Falah-Hassani K, Reeves J, Shiri R, Hickling D, McLean L. The pathophysiology of stress urinary incontinence: a systematic review and meta-analysis. Int Urogynecol J. 2021;32(3):501-52.

7. Dumoulin C, Hay-Smith J, Habee-Seguin GM, Mercier J. Pelvic floor muscle training versus no treatment, or inactive control treatments, for urinary incontinence in women: a short version Cochrane systematic review with meta-analysis. Neurourol Urodyn. 2015;34(4):300-8.

8. Kruger J, Budgett D, Goodman J, Bo K. Can you train the pelvic floor muscles by contracting other related muscles? Neurourol Urodyn. 2019;38(2):677-83.

9. Tuttle LJ, DeLozier ER, Harter KA, Johnson SA, Plotts CN, Swartz JL. The Role of the Obturator Internus Muscle in Pelvic Floor Function. Journal of Women's Health Physical Therapy. 2016;40(1):15-9.

10. Thompson JA, O'Sullivan PB, Briffa NK, Neumann P. Altered muscle activation patterns in symptomatic women during pelvic floor muscle contraction and Valsalva manouevre. Neurourol Urodyn. 2006;25(3):268-76.

11. Underwood DB, Calteaux TH, Cranston AR, Novotny SA, Hollman JH. Hip and pelvic floor muscle strength in women with and without stress urinary incontinence: A ccase-control study. Journal of Women's Health Physical Therapy. 2012;36(1):55-61.

12. O'Sullivan PB, Grahamslaw KM, Kendell M, Lapenskie SC, Moller NE, Richards KV. The effect of different standing and sitting postures on trunk muscle activity in a pain-free population. Spine (Phila Pa 1976). 2002;27(11):1238-44.

13. Neumann DA. Kinesiology of the hip: a focus on muscular actions. J Orthop Sports Phys Ther. 2010;40(2):82-94.

14. Lindsay DM, Maitland M, Lowe RC, Kane TJ. Comparison of isokinetic internal and external hip rotation torques using different testing positions. J Orthop Sports Phys Ther. 1992;16(1):43-50.

15. Capson AC, Nashed J, McLean L. The role of lumbopelvic posture in pelvic floor muscle activation in continent women. J Electromyogr Kinesiol. 2011;21(1):166-77.

16. Chen CH, Huang MH, Chen TW, Weng MC, Lee CL, Wang GJ. Relationship between ankle position and pelvic floor muscle activity in female stress urinary incontinence. Urology. 2005;66(2):288-92.

17. Chen HL, Lin YC, Chien WJ, Huang WC, Lin HY, Chen PL. The effect of ankle position on pelvic floor muscle contraction activity in women. J Urol. 2009;181(3):1217-23.

18. Sapsford RR, Richardson CA, Stanton WR. Sitting posture affects pelvic floor muscle activity in parous women: an observational study. Aust J Physiother. 2006;52(3):219-22.

19. Frawley HC, Galea MP, Phillips BA, Sherburn M, Bo K. Effect of test position on pelvic floor muscle assessment. Int Urogynecol J Pelvic Floor Dysfunct. 2006;17(4):365-71.

20. Morgan DM, Kaur G, Hsu Y, Fenner DE, Guire K, Miller J, et al. Does vaginal closure force differ in the supine and standing positions? Am J Obstet Gynecol. 2005;192(5):1722-8.

21. Lee K. Investigation of Electromyographic Activity of Pelvic Floor Muscles in Different Body Positions to Prevent Urinary Incontinence. Med Sci Monit. 2019;25:9357-63.

22. Bo K, Finckenhagen HB. Is there any difference in measurement of pelvic floor muscle strength in supine and standing position? Acta Obstet Gynecol Scand. 2003;82(12):1120-4.

23. Gimenez MM, Fitz FF, de Azevedo Ferreira L, Bortolini MAT, Lordelo PVS, Castro RA. Pelvic floor muscle function differs between supine and standing positions in women with stress urinary incontinence: an experimental crossover study. J Physiother. 2022;68(1):51-60.

24. Mastwyk S, McClelland J, Cooper MM, Frawley HC. Pelvic floor muscle function in the standing position in women with pelvic floor dysfunction. Int Urogynecol J. 2021.

25. Kelly M, Tan BK, Thompson J, Carroll S, Follington M, Arndt A, et al. Healthy adults can more easily elevate the pelvic floor in standing than in crook-lying: an experimental study. Aust J Physiother. 2007;53(3):187-91.

26. Moser H, Luginbuehl H, Baeyens JP, Radlinger L. Reliability and validity of pelvic floor muscle displacement measurements during voluntary contractions. Int Urogynecol J. 2019;30(12):2093-100.

27. Devreese A, Staes F, De Weerdt W, Feys H, Van Assche A, Penninckx F, et al. Clinical evaluation of pelvic floor muscle function in continent and incontinent women. Neurourol Urodyn. 2004;23(3):190-7.

28. Deindl FM, Vodusek DB, Hesse U, Schussler B. Pelvic floor activity patterns: comparison of nulliparous continent and parous urinary stress incontinent women. A kinesiological EMG study. Br J Urol. 1994;73(4):413-7.

29. Morkved S, Salvesen KA, Bo K, Eik-Nes S. Pelvic floor muscle strength and thickness in continent and incontinent nulliparous pregnant women. Int Urogynecol J Pelvic Floor Dysfunct. 2004;15(6):384-9; discussion 90.

30. Madill SJ, Harvey MA, McLean L. Women with SUI demonstrate motor control differences during voluntary pelvic floor muscle contractions. Int Urogynecol J Pelvic Floor Dysfunct. 2009;20(4):447-59.

31. Smith MD, Coppieters MW, Hodges PW. Postural response of the pelvic floor and abdominal muscles in women with and without incontinence. Neurourol Urodyn. 2007;26(3):377-85.

32. Madill SJ, Harvey MA, McLean L. Women with stress urinary incontinence demonstrate motor control differences during coughing. J Electromyogr Kinesiol. 2010;20(5):804-12.

33. Smith MD, Coppieters MW, Hodges PW. Postural activity of the pelvic floor muscles is delayed during rapid arm movements in women with stress urinary incontinence. Int Urogynecol J Pelvic Floor Dysfunct. 2007;18(8):901-11.

34. Thompson JA, O'Sullivan PB. Levator plate movement during voluntary pelvic floor muscle contraction in subjects with incontinence and prolapse: a cross-sectional study and review. Int Urogynecol J Pelvic Floor Dysfunct. 2003;14(2):84-8.

35. Thompson JA, O'Sullivan PB, Briffa NK, Neumann P. Differences in muscle activation patterns during pelvic floor muscle contraction and Valsalva maneuver. Neurourol Urodyn. 2006;25(2):148-55.

36. Sapsford RR, Richardson CA, Maher CF, Hodges PW. Pelvic floor muscle activity in different sitting postures in continent and incontinent women. Arch Phys Med Rehabil. 2008;89(9):1741-7.

37. Burti JS, Hacad CR, Zambon JP, Polessi EA, Almeida FG. Is there any difference in pelvic floor muscles performance between continent and incontinent women? Neurourol Urodyn. 2015;34(6):544-8.

38. Cerruto MA, Vedovi E, Mantovani W, D'Elia C, Artibani W. Effects of ankle position on pelvic floor muscle electromyographic activity in female stress urinary incontinence: preliminary results from a pilot study. Arch Ital Urol Androl. 2012;84(4):184-8.

39. Lee K. Activation of Pelvic Floor Muscle During Ankle Posture Change on the Basis of a Three-Dimensional Motion Analysis System. Med Sci Monit. 2018;24:7223-30.

40. Ptaszkowski K, Zdrojowy R, Slupska L, Bartnicki J, Dembowski J, Halski T, et al. Assessment of bioelectrical activity of pelvic floor muscles depending on the orientation of the pelvis in menopausal women with symptoms of stress urinary incontinence: continued observational study. Eur J Phys Rehabil Med. 2017;53(4):564-74.

41. Ptaszkowski K, Zdrojowy R, Ptaszkowska L, Bartnicki J, Taradaj J, Paprocka-Borowicz M. Electromyographic evaluation of synergist muscles of the pelvic floor muscle depending on the pelvis setting in menopausal women: A prospective observational study. Gait Posture. 2019;71:170-6.

42. Halski T, Slupska L, Dymarek R, Bartnicki J, Halska U, Krol A, et al. Evaluation of bioelectrical activity of pelvic floor muscles and synergistic muscles depending on orientation of pelvis in menopausal women with symptoms of stress urinary incontinence: a preliminary observational study. Biomed Res Int. 2014;2014:274938.

43. Messelink B, Benson T, Berghmans B, Bo K, Corcos J, Fowler C, et al. Standardization of terminology of pelvic floor muscle function and dysfunction: report from the pelvic floor clinical assessment group of the International Continence Society. Neurourol Urodyn. 2005;24(4):374-80.

44. Deindl FM, Vodusek DB, Hesse U, Schussler B. Activity patterns of pubococcygeal muscles in nulliparous continent women. Br J Urol. 1993;72(1):46-51.

45. Avery K, Donovan J, Peters TJ, Shaw C, Gotoh M, Abrams P. ICIQ: a brief and robust measure for evaluating the symptoms and impact of urinary incontinence. Neurourol Urodyn. 2004;23(4):322-30.

46. Uebersax JS, Wyman JF, Shumaker SA, McClish DK, Fantl JA. Short forms to assess life quality and symptom distress for urinary incontinence in women: the Incontinence Impact Questionnaire and the Urogenital Distress Inventory. Continence Program for Women Research Group. Neurourol Urodyn. 1995;14(2):131-9.

47. Klovning A, Avery K, Sandvik H, Hunskaar S. Comparison of two questionnaires for assessing the severity of urinary incontinence: The ICIQ-UI SF versus the incontinence severity index. Neurourol Urodyn. 2009;28(5):411-5.

48. Laycock J. Pelvic muscle exercises: physiotherapy for the pelvic floor. Urol Nurs. 1994;14(3):136-40.

49. Reissing ED, Brown C, Lord MJ, Binik YM, Khalife S. Pelvic floor muscle functioning in women with vulvar vestibulitis syndrome. J Psychosom Obstet Gynaecol. 2005;26(2):107-13.

50. Keshwani N, McLean L. Development of a differential suction electrode for improved intravaginal recordings of pelvic floor muscle activity: reliability and motion artifact assessment. Neurourol Urodyn. 2012;31(8):1272-8.

51. Auchincloss CC, McLean L. The reliability of surface EMG recorded from the pelvic floor muscles. J Neurosci Methods. 2009;182(1):85-96.

52. Madill SJ, McLean L. Quantification of abdominal and pelvic floor muscle synergies in response to voluntary pelvic floor muscle contractions. J Electromyogr Kinesiol. 2008;18(6):955-64.

53. Fritz CO, Morris PE, Richler JJ. Effect size estimates: current use, calculations, and interpretation. J Exp Psychol Gen. 2012;141(1):2-18.

54. Obloza A, Teo R, Marriott E, Parker G, Tincello D. Association of baseline severity of lower urinary tract symptoms with the success conservative therapy for urinary incontinence in women. International Urogynecology Journal. 2019;30(5):705-10.

55. Brooks KCL, Varette K, Harvey M-A, Robert M, Brison RJ, Day A, et al. A model identifying characteristics predictive of successful pelvic floor muscle training outcomes among women with stress urinary incontinence. International Urogynecology Journal. 2021;32(3):719-28.

56. Dufour S, Wu M. No. 397 - Conservative Care of Urinary Incontinence in Women. J Obstet Gynaecol Can. 2020;42(4):510-22.

57. Bordeianou LG, Anger JT, Boutros M, Birnbaum E, Carmichael JC, Connell KA, et al. Measuring Pelvic Floor Disorder Symptoms Using Patient-Reported Instruments: Proceedings of the Consensus Meeting of the Pelvic Floor Consortium of the American Society of Colon and Rectal Surgeons, the International Continence Society, the American Urogynecologic Society, and the Society of Urodynamics, Female Pelvic Medicine and Urogenital Reconstruction. Female Pelvic Med Reconstr Surg. 2020;26(1):1-15.

58. Li B, Zhu L, Xu T, Lang J. The optimal threshold values for the severity of urinary incontinence based on the 1-hour pad test. Int J Gynaecol Obstet. 2012;118(2):117-9.

59. Zhu L, Lang JH, Chen J, Chen J. Morphologic study on levator ani muscle in patients with pelvic organ prolapse and stress urinary incontinence. Int Urogynecol J Pelvic Floor Dysfunct. 2005;16(5):401-4.

60. Gilpin SA, Gosling JA, Smith AR, Warrell DW. The pathogenesis of genitourinary prolapse and stress incontinence of urine. A histological and histochemical study. Br J Obstet Gynaecol. 1989;96(1):15-23.

61. Carriere B, Feldt C. The Pelvic Floor. New York, NY: Thieme; 2006.

62. El_Shamy FF, Mohran AA. Effect of pelvic postural changes on pelvic floor muscle activity in women with stress urinary incontinence Bulletin of Faculty of Physical Therapy. 2013;18(1):9-14.

63. Keshwani N, McLean L. A differential suction electrode for recording electromyographic activity from the pelvic floor muscles: crosstalk evaluation. Journal of electromyography and kinesiology : official journal of the International Society of Electrophysiological Kinesiology. 2013;23(2):311-8.

64. Halski T, Ptaszkowski K, Slupska L, Dymarek R, Paprocka-Borowicz M. Relationship between lower limb position and pelvic floor muscle surface electromyography activity in menopausal women: a prospective observational study. Clin Interv Aging. 2017;12:75-83.

65. Nguyen JK, Lind LR, Choe JY, McKindsey F, Sinow R, Bhatia NN. Lumbosacral spine and pelvic inlet changes associated with pelvic organ prolapse. Obstet Gynecol. 2000;95(3):332-6.

66. Tosun OC, Dayican DK, Keser I, Kurt S, Yildirim M, Tosun G. Are clinically recommended pelvic floor muscle relaxation positions really efficient for muscle relaxation? Int Urogynecol J. 2022.

67. Keshwani N, McLean L. State of the art review: Intravaginal probes for recording electromyography from the pelvic floor muscles. Neurourol Urodyn. 2015;34(2):104-12.

68. Auchincloss C, McLean L. Does the presence of a vaginal probe alter pelvic floor muscle activation in young, continent women? J Electromyogr Kinesiol. 2012;22(6):1003-9.

69. McLean L, Normandeau C, Hodder J. The impact of state of bladder fullness on tonic and phasic activation of the pelvic floor muscles in women. J Electromyogr Kinesiol. 2016;27:60-5.

Chapter 4

The effect of hip position on pelvic floor muscle activation in women with and without stress urinary incontinence

4.1 Abstract

The aims of this study were to determine if pelvic floor muscle (PFM) activation amplitudes differ between continent women and those with stress urinary incontinence (SUI) and to describe changes in PFM activation that occur when hip position is altered. This was an observational cohort study. Thirty-six eligible participants were recruited and stratified into three cohorts: women without incontinence (n = 15), women with mild SUI (n = 11), and women with moderate SUI (n = 13). Electromyographic (EMG) signals were recorded from the PFMs while participants were at rest and while performing maximal effort PFM contractions in supine, assuming different hip flexion and hip rotation positions. The effect of continence status was determined using the Kruskal-Wallis test and Friedman's test was used to examine the effect of hip position on tonic and maximal PFM activity. Post-hoc analyses were performed to determine pairwise differences, where alpha ($\alpha = 0.05$) was adjusted using a Bonferroni correction. Women without SUI (29.8 ± 13.7 years) were younger ($p = 0.002$) than those with SUI (mild SUI aged 46.1 ± 14.4 years; moderate SUI aged 46.0 ± 10.4 years). Those with moderate SUI consistently generated lower maximum PFM activation amplitudes ($p \leq 0.011$) than participants in the other groups. Tonic PFM activation amplitudes were lower when the hips were flexed to 90° compared to when they were fully extended in participants

without symptoms (z = - 2.262, p = 0.024) and those with moderate SUI (z = - 3.157, p = 0.002) but not in those with mild SUI (z = -1.371, p = 0.170). Tonic activation was higher in women who were continent when the hips were in medial rotation, both when the hips were extended (z = -2.870, p = 0.004*)* and flexed (z = -2.778, p = 0.005). Among participants with mild SUI, tonic PFM activation was higher when the hips were in medial (z = -4.208, $p \leq 0.001$*)* and lateral (z = -3.797, $p \leq 0.001$*)* rotation compared to neutral, but only when the hips were extended. Participants with moderate SUI did not demonstrate any effect of hip rotation on tonic PFM activity. Compared to participants with mild SUI, those with moderate symptoms generated lower PFM activation amplitudes, suggesting the potential for different underlying pathophysiology of SUI based on severity stratification. Hip position influenced PFM tonic and maximum PFM activity, where the effect depended on continence status and severity. In a clinical population, adjusting hip flexion and rotation postures may be worthwhile to facilitate PFM activation or reduce unwanted activation.

4.2 Introduction

An effective pelvic floor muscle (PFM) contraction is important to the continence mechanism, especially during coughing, laughing, and sneezing, which are tasks that lead to sharp rises in intra-abdominal pressure (1). Stress urinary incontinence (SUI) is the unwanted leaking of urine when bladder pressure exceeds urethral pressure (2). The PFMs support the bladder neck and urethra, and their contraction contributes to urethral closure pressure, which can mitigate urine leakage (3). The PFMs are under voluntary

and involuntary control and are believed to work in synergy with the abdominal and hip muscles (4-12).

Mounting evidence suggests that the hip muscles may contribute to continence control by complementing PFM contraction. Hip range of motion and hip muscle strength were reported to be altered in women with SUI (13, 14), while others have found positive changes in continence control in response to hip strengthening exercise (6, 8, 11, 13). In Jordre and Schweinle (6), while examining the effect of a pelvic floor muscle training (PFMT) program on symptoms of SUI, women in a control group were assigned isolated hip rotation strengthening exercises without instruction to contract their PFMs. After six weeks of training, both groups demonstrated a significant reduction in the frequency of urine leakage, lower scores on two standardized questionnaires indicative of symptom severity, and a significant improvement in their condition using a subjective rating scale. Likewise, Tuttle et al. (8) reported increased PFM strength in young women after a 12-week training program involving a series of hip lateral rotation strengthening exercises without any specific PFM exercises. The findings were consistent when the study was repeated in a cohort of older women (11). Others have reported improved continence following post-operative rehabilitation for total hip arthroscopy (THA), where hip strengthening exercises were prescribed without PFM training, suggesting a link between hip muscle conditioning and improvements in urinary incontinence symptoms (15-17).

The effect of body position and lumbopelvic postures on PFM activity, strength, and/or morphometry has been described (18-27). The influence of posture on urinary incontinence was highlighted in a study that reported the volume of urine leakage during coughing could be reduced by moving from an upright standing posture to a crossed leg

posture, with and without leaning the trunk forward (28). The PFMs, specifically the iliococcygeus and pubococcygeus portions of the levator ani, also have a broad soft tissue connection with the lateral pelvic wall as it connects to the obturator fascia (29), the tendinous arch of the levator ani (ATLA) and the tendinous arch of the pelvic fascia (ATPF). The tendinous arches (ATLA, ATFP) are thickened, dense connective tissues that originate from the fascia covering the superior portion of the obturator internus muscles and span between the pubic bone and the ischial spine like guy wires to provide a stable lateral anchor for the PFMs (30). This myofascial connection acts as an anchor point for the PFMs (29). The obturator internus muscles attach to the medial aspect of each respective femoral condyle along with the other short lateral rotator muscles of the hip (30, 31). There is evidence that the length of the obturator internus muscle is altered when the hip is in different positions (32). It has been reported using cadavers and string models that the obturator internus muscle is elongated when the hip is in medial rotation and when it is flexed more than 60 degrees (32). Although it can be appreciated that the obturator internus muscle would shorten when the hip is in lateral rotation, the influence of lateral rotation on muscle tension will depend on whether the obturator internus muscle is isometrically contracting or in a resting state. Thus, altering hip rotation and hip flexion positions may influence PFM length, tension, and, consequently, activation. Given the close anatomical and functional relationship between the pelvic floor and hip muscles and the reported SUI symptom improvement with hip muscle strengthening alone, hip position might influence the activation of the PFMs. However, the effect of hip position on PFM activation has not been evaluated.

This study aimed to evaluate the impact of changes in hip flexion and hip rotation position on the tonic and maximal activation of the PFMs in women with and without stress urinary incontinence.

4.3 Methods

Participant recruitment, screening, and clinical assessments are described in Chapter 3 (3.3 Methods), where participant instrumentation for EMG acquisition is also described in full. The protocol to evaluate EMG activation under different hip positions is described below.

4.3.1 Hip Positions

Participants remained supine and assumed three variations of hip rotation with the hips extended (Figure 4.1) and the hips and knees flexed to 90° with the lower legs fully supported on a height-adjustable table (Figure 4.2). The three hip rotation positions were neutral rotation, lateral rotation (LR), and medial rotation (MR). The researcher asked participants to maximally rotate their hips, and to maintain the position without active muscle contraction once in position. The neutral rotation position was achieved by keeping the hips neutral with no rotation. While lying supine, the amount of hip abduction was held constant by placing a 9.5 cm wide bolster between the participant's knees; participants were instructed to maintain contact with the bolster without squeezing it (Figure 4.1). The influence of hip flexion on PFM activation was evaluated by recording EMG data while the hips were flexed to 90 degrees and fully extended, keeping the hips in neutral rotation (Figure 4.2A). When the hips and knees were flexed, LR was achieved by having participants approximate their feet and abduct their hips while their

thighs rotated laterally. Their knees moved towards the outer edge of the height-adjustable stool (a clamshell position) (Figure 4.2B *middle*). MR was achieved by having participants adduct their hips and approximate their knees while keeping their feet at the outer edge of the height-adjustable stool (Figure 4.2B *right*).

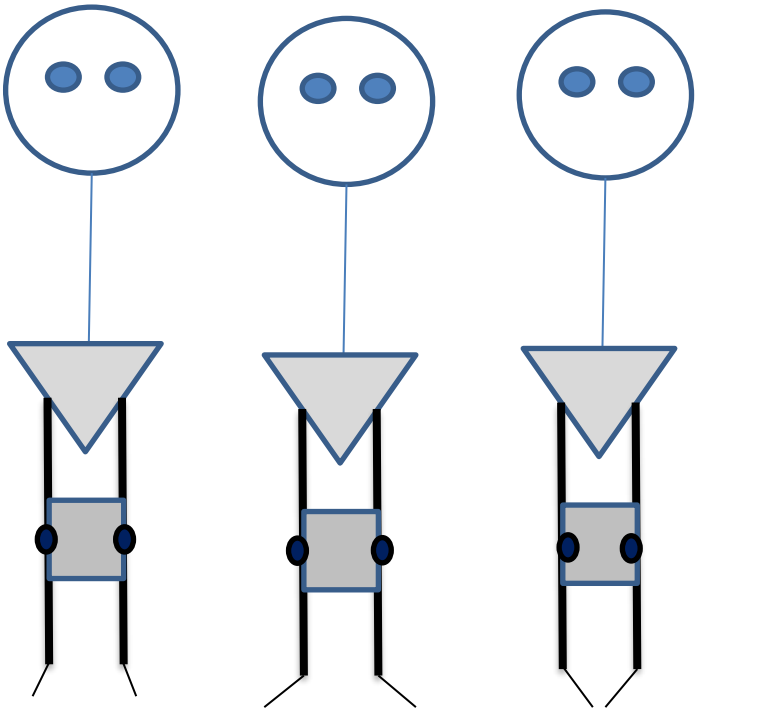

Figure 4.1 Hip rotation positions supine with hips extended

Left: neutral rotation, *middle:* lateral rotation (LR), and *right:* medial rotation (MR). The grey rectangle demonstrates the position of the 9.5 cm bolster that was used to standardize the amount of hip abduction.

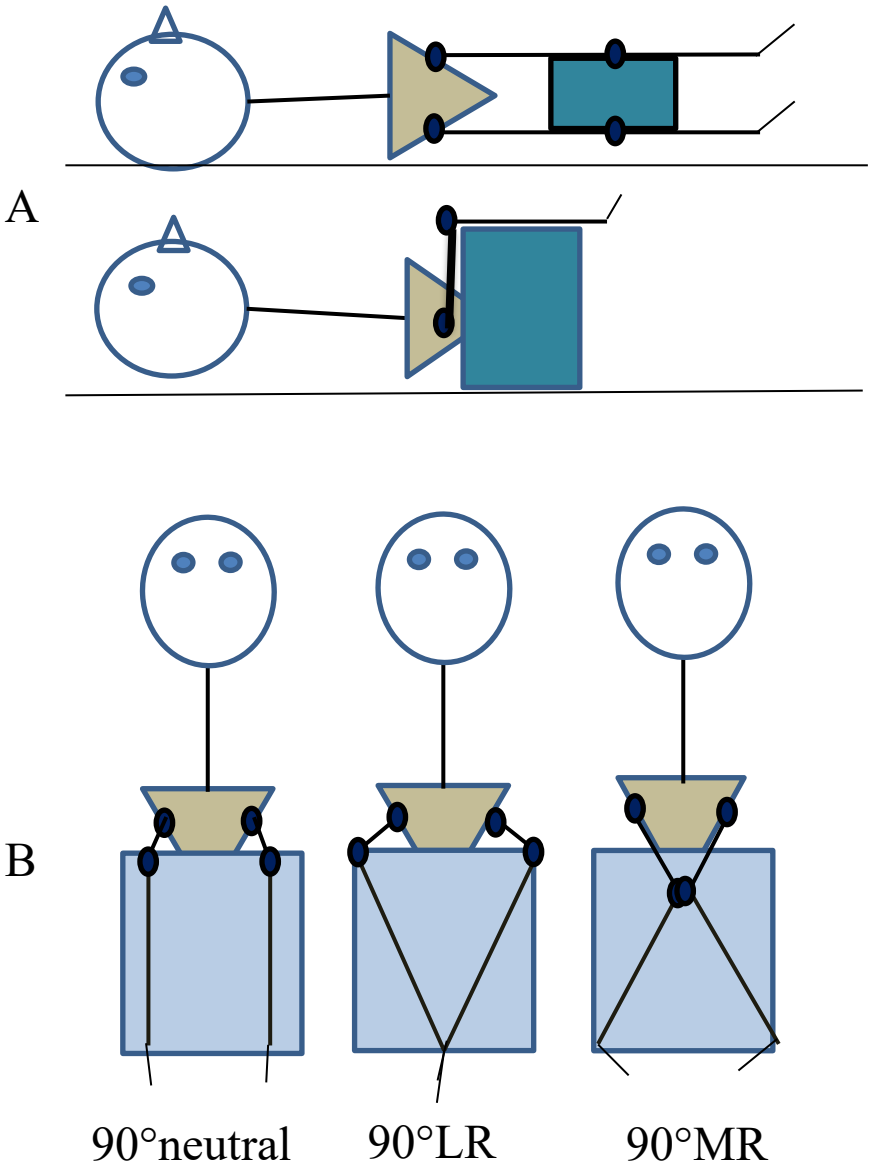

Figure 4.2 Hip flexion and rotation positions with hips and knees flexed to 90°

A: Hip flexion positions: *Upper*: supine lying with hips fully extended and neutral rotation, *Lower*: tabletop lying with 90°of hip flexion and neutral rotation. **B:** *Left:* tabletop lying with neutral hip rotation (Neutral), *Middle:* tabletop lying with lateral rotation (LR), and *Right:* tabletop lying with medial rotation (MR).

4.4 Results

Refer to Chapter 3 (3.4 Results) for the participant flowchart (Figure 3.3) and a complete description of participant demographics and group characteristics.

4.4.1 The effect of continence on PFM activity

Tonic PFM activation was mostly consistent among the three groups when different hip positions were assumed, except for when the hips were in lateral rotation. In this position, higher amplitudes of tonic activity were detected in participants with mild SUI (*median* 4.65 uV, *IQR* 2.94 uV, mean rank 44.55) compared to participants with more severe SUI symptoms (*median* 3.20 uV, *IQR* 3.0 uV, mean rank 29.69). The amplitude of maximal PFM activity was higher in the continent and mild SUI groups compared to the moderate SUI group in all test positions, with a moderate effect size (Table 4.1).

Table 4.1 The effect of continence status on maximal PFM activity in different hip positions

	Group				Pairwise Differences		
	Continent (n = 15)	Mild SUI (n = 11)	Moderate SUI (n = 13)	*Kruskal Wallis Test Group main effect* $\alpha = 0.05$	Pairs	*Mann-Whitney* $\alpha = 0.017$	*Effect size (r)*
No hip flexion							
No Rotation (Neutral)							
Median (IQR) *uV*	37.49(20.66)	41.79(37.20)	28.18(17.01)	***H* = 12.78, *p* = 0.002**	Cont Mild	$p = 0.387$	$r = 0.10$
Mean rank	63.5	67.8	42.4		Cont Mod	***p* = 0.002**	***r* = 0.35**
					Mild Mod	***p* = 0.004**	***r* = 0.34**
Lateral Rotation (LR)							
Median (IQR) *uV*	37.89(17.53)	41.71(29.56)	28.03(16.08)	***H* = 17.70, *p* < 0.001**	Cont Mild	$p = 0.123$	$r = 0.19$
Mean rank	62.1	72.0	40.3		Cont Mod	***p* = 0.001**	***r* = 0.36**
					Mild Mod	***p* = 0.010**	***r* = 0.35**
Medial Rotation (MR)							
Median (IQR) *uV*	35.56(22.74)	38.58(29.74)	28.47(14.16)	***H* = 7.64, *p* = 0.022**	Cont Mild	$p = 0.709$	$r = 0.04$
Mean rank	63.4	64.0	45.6		Cont Mod	***p* = 0.007**	***r* = 0.30**
					Mild Mod	***p* < 0.001**	***r* = 0.44**
90° Hip Flexion							
No Rotation (90°)							
Median (IQR) *uV*	35.83(21.37)	42.79(28.28)	29.00(16.08)	***H* = 7.09, *p* = 0.029**	Cont Mild	$p = 0.407$	$r = 0.11$
Mean rank	48.1	53.9	35.7		Cont Mod	$p = 0.057$	$r = 0.23$
					Mild Mod	***p* = 0.011**	***r* = 0.35**
LR (90°LR)							
Median (IQR) *uV*	41.98(31.72)	32.66(28.03)	26.48(12.85)	***H* = 13.36, *p* = 0.001**	Cont Mild	$p = 0.478$	$r = 0.09$
Mean rank	54.2	50.0	31.5		Cont Mod	***p* = 0.001**	***r* = 0.42**
					Mild Mod	***p* = 0.007**	***r* = 0.37**
MR (90°MR)							
Median (IQR) *uV*	33.72(20.30)	37.30(22.79)	24.79(16.96)	***H* = 9.66, *p* = 0.008**	Cont Mild	$p = 0.952$	$r = 0.01$
Mean rank	51.3	51.9	33.4		Cont Mod	***p* = 0.008**	***r* = 0.32**
					Mild Mod	***p* = 0.006**	***r* = 0.37**

PFM pelvic floor muscle; SUI stress urinary incontinence; LR (hip lateral rotation); MR (hip medial rotation); IQR interquartile range; *uV* microvolt. Cont women without SUI; Mild women with mild SUI, Mod women with moderate SUI.

4.4.2 The effect of hip position on PFM activity

Hip position significantly affected the amplitude of tonic PFM activity across all groups (Table 4.2). Among continent participants, hip medial rotation resulted in larger amplitudes of tonic activity compared to no hip rotation, both when the hips were flexed to 90° and when the hips were extended. Among women with mild SUI, the amplitude of tonic PFM activity was higher in both medial and lateral rotation compared to no rotation, but only when the hips were extended. Participants with moderate SUI did not demonstrate differences in tonic PFM activity among the different hip rotation positions. Finally, in women with moderate SUI and continent women, tonic activation of the PFMs was lower in the hip flexed position than in the hip extended position. Where differences were significant, the effect sizes were large (Table 4.2).

Hip position significantly affected the amplitude of maximal PFM activity, and the effect was dependent on continence status (Table 4.3). The continent group demonstrated higher amplitudes of maximal PFM activity in supine with the hips extended compared to the hip flexion position. When the hips were flexed, they generated higher EMG activity in neutral rotation compared to lateral rotation. In contrast, hip flexion did not influence maximal activity in participants with SUI compared to extension, and hip rotation, especially medial rotation, was associated with lower maximal PFM activity among participants with SUI.

Table 4.2 The effect of hip position on tonic PFM activation

Position Main Effects for Each Group									
	Continent (n = 15)			**Mild SUI** (n = 11)			**Moderate SUI** (n = 13)		
	χ2* = 15.736, *p* = 0.008			***χ2* = 26.333, *p* < 0.001***			***χ2* = 26.248, *p* < 0.001***		
Pairwise Comparisons									
	Continent			**Mild SUI**			**Moderate SUI**		
	Median (IQR) *uV*	Wilcoxon	Effect Size *(r)*	Median (IQR) *uV*	Wilcoxon	Effect Size *(r)*	Median (IQR) *uV*	Wilcoxon	Effect Size *(r)*
Hip Flexion									
Supine	3.48 (3.79)			2.77 (1.85)			3.12 (3.62)		
		z* = -2.262, *p* = 0.024	0.38		*z* = -1.371, *p* = 0.170	0.24		***z* = -3.157, *p* = 0.002***	0.51
Hips 90°	2.04 (1.57)			2.57 (1.31)			2.51 (2.03)		
α = 0.025									
Rotation I									
0°Flexion									
Supine vs	3.48 (3.79)			2.77 (1.85)			3.12 (3.62)		
LR	4.11 (5.38)	*z* = -1.394, *p* = 0.163	0.23	4.62 (2.94)	***z* = -4.208, p < 0.001***	0.73	3.25 (2.97)	*z* = -0.321, *p* = 0.748	0.05
MR	4.22 (2.85)	***z* = -2.870, *p* = 0.004***	0.48	4.43 (5.34)	***z* = -3.797, p < 0.001***	0.66	3.12 (3.18)	*z* = -0.183, *p* = 0.680	0.03
α = 0.017									
Rotation II									
90°Flexion									
90°Flexion vs	2.04 (1.57)			2.57 (1.31)			2.51 (2.03)		
90_LR	2.48 (1.72)	*z* = -2.135, *p* = 0.033‡	0.36	2.61 (2.86)	*z* = -0.371, *p* = 0.710	0.06	2.71 (4.90)	*z* = -1.676, p = 0.094	0.27
90_MR	2.67 (2.24)	***z* = -2.778, *p* = 0.005***	0.46	3.09 (1.19)	*z* = -1.400, *p* = 0.162	0.24	3.13 (4.07)	*z* = -0.627, p = 0.530	0.10
α = 0.017									

PFM (pelvic floor muscle). LR (hip lateral rotation). MR (hip medial rotation). The test statistic and associated p-value are reported, with * indicating a significant posture effect and ‡ indicating a trend. Friedman's analysis of variance by ranks was used to test for position main effects, and Wilcoxon signed ranks test for pairwise comparison.

Table 4.3 The effect of hip position on maximal PFM activation

Position Main Effects for Each Group (α = 0.05)									
	Continent (n = 15)			**Mild SUI** (n = 11)			**Moderate SUI** (n = 13)		
	χ2* = 27.84, *p* < 0.001			***χ2* = 12.810, *p* < 0.025***			***χ2* = 17.543, *p* < 0.004***		
Pairwise Comparisons									
	Continent			**Mild SUI**			**Moderate SUI**		
	Median (IQR) *uV*	Wilcoxon	Effect Size *(r)*	Median (IQR) *uV*	Wilcoxon	Effect Size *(r)*	Median (IQR) *uV*	Wilcoxon	Effect Size *(r)*
Hip Flexion									
Hips 0°	**37.49 (20.66)**	***z* = - 2.702 *p* = 0.024**	**0.42**	41.79 (37.20)	*z* = - 0.371 *p* = 0.710	0.06	28.18 (17.01)	*z* = - 0.319 *p* = 0.750	0.05
Hips 90°	**35.83 (21.37)**			42.79 (28.28)			29.00 (16.08)		
α = 0.025									
Hip extended position									
neutral vs	37.49 (20.66)			41.79 (37.20)			**28.18 (17.01)**		
LR	37.89 (17.53)	*z* = - 0.494 *p* = 0.621	0.08	41.71 (29.56)	*z* = - 0.456 *p* = 0.649	0.08	31.21 (15.21)	*z* = - 0.140 *p* = 0.889	0.02
MR	36.56 (22.74)	*z* = - 0.281 *p* = 0.778	0.04	38.58 (29.74)	*z* = - 1.295 *p* = 0.195	0.23	**29.13 (12.84)**	***z* = -2.386 *p* = 0.017**	**0.38**
α = 0.017									
Hip flexed position									
neutral vs	**35.83 (21.37)**			**42.79 (28.28)**			**29.00 (16.08)**		
LR	**41.98 (31.72)**	***z* = - 3.765 *p* = 0.001***	**0.58**	32.66 (28.03)	*z* = -1.943, *p* = 0.052	0.34	**27.67 (12.46)**	***z* = - 3.219 *p* = 0.001***	**0.52**
MR	33.72 (20.30)	*z* = - 0.220 *p* = 0.826	0.03	**37.30 (22.79)**	***z* = - 2.571 *p* = 0.010**	**0.45**	**25.04 (15.95)**	***z* = - 3.795 *p* < 0.001***	**0.61**
α = 0.017									

PFM (pelvic floor muscle). LR (hip lateral rotation). MR (hip medial rotation). The test statistic and associated p-value are reported, with * indicating a significant posture effect. Friedman's analysis of variance by ranks was used to test for position main effects, and Wilcoxon signed ranks test for pairwise comparison. Effect size (r) = z-score divided by the square root of the number of samples computed within each group for each comparison of positions.

4.5 Discussion

This exploratory study examined the effect of hip flexion and rotation on PFM activation. The results support the hypothesis that hip position affects PFM activation in women who are continent and in those with SUI. However, the differences in tonic and phasic activation amplitudes in response to the different hip positions varied among the groups. Overall, tonic activation does not appear to be affected by continence status. In contrast, maximal activation of the PFMs during MVC was consistently lower in women with moderate symptoms of SUI compared to women with mild SUI and compared to women who were continent.

PFM activation and continence status

Tonic PFM activation amplitudes were similar between women with and without SUI. Participants were lying in an antigravity position where the demands on postural control and the continence system were minimal. In one position, supine lying with hip lateral rotation, higher tonic activation amplitudes were detected in women with mild SUI compared to the group with moderate SUI; however, this was an isolated finding in a small sample, and thus could be spurious. The findings are consistent with and complementary to those of Burti et al. (33). However, in addition to observing consistent tonic activation in women with and without SUI, the findings demonstrate between group consistency through multiple positions. Participants in the Burti et al. (33) study were trained by physiotherapy instruction, digital palpation, and EMG biofeedback to contract and relax their PFMs. Sufficient time was taken for participants to relax before recording the resting data. Providing time and space to train a resting state likely contributed to all

groups achieving consistent tonic activity despite differences in continence status. In situations where higher tonic PFM activation has been reported in women with SUI, altered motor control strategies may have been adopted to control continence or to enhance lumbopelvic stability (34-36), or perhaps there was not enough time provided for participants to relax (37). Conversely, in a small sample of women, Sapsford et al. (26) reported lower levels of tonic PFM activity in participants with SUI compared to continent participants while they assumed different sitting positions, suggesting the possibility of PFM insufficiency among the participants with SUI. With multiple factors contributing to tonic activation, such as body position, state of relaxation, and neuromuscular integrity of the PFMs, we still need to fully understand the implication of altered tonic activation on continence control.

Maximal activation amplitudes recorded while PFM voluntary contractions were performed were higher in continent participants and participants with mild SUI than in those with moderate SUI. This finding was consistent across all the hip positions, indicating that PFM excitability during voluntary PFM contractions may be diminished in those with moderate SUI but not in those with milder symptoms. Madill et al. (38) also subdivided women with SUI by severity of symptoms. They detected higher activation amplitudes during PFM MVCs in the continent women than those with mild and more severe symptoms. While performing a standing load-catching task, Smith et al. (36) reported higher PFM activation in the symptomatic group than in the asymptomatic group before and after the task. They discovered that by subdividing the symptomatic group by severity, the difference was significant only in those with milder symptoms.

While performing a load-catching task in standing, the PFMs contribute to postural stability. They are in a state of readiness, which is not the same as tonic activity at rest and is also different than activation generated during voluntary MVCs. The higher activation amplitudes identified in participants with mild SUI may indicate that those with mild incontinence utilize more PFM activity to stabilize and prepare for situations challenging postural stability or continence. Functional deficits in PFM performance in women with incontinence have been identified, such as lower endurance (39, 40), lower strength (39, 41), lower rate of force production (42), and altered motor control (36, 38).

The effect of hip position on PFM activation

This exploratory study focused on the influence of hip position on PFM activation. The unique myofascial features of the lumbopelvic area allow tension across the PFMs, position of the pelvic diaphragm, and intra-abdominal pressure to be modified by assuming different positions. Because of this, it was hypothesized that PFM activity would be either facilitated or inhibited by altering hip position.

Positions recommended by physiotherapists to reduce excess PFM tension, normalize high tone, and promote PFM relaxation often include some hip flexion, where the abdominal muscles are also relaxed (43). Tosun et al. (43) reported a reduction in tonic PFM activity and rectus abdominis activity in positions where the hips were flexed (modified butterfly, child pose, and a deep squat). A similar effect was observed in the present study, tonic PFM activity was lower when the hips were flexed than when they were extended in two of the three cohorts (continent and moderate SUI groups). Tosun et al. (43) hypothesized that when the hips are flexed to 90°, the tension across the distal

attachments of the abdominal muscles and associated fascia are minimized. Less tension on the abdominal muscles should reduce intra-abdominal pressure and limit pressures directed to the pelvic floor.

Hip flexion did not alter tonic PFM in women with mild SUI symptoms; the exact reason is unknown. Those with mild SUI symptoms may habitually use guarding and bracing techniques to maintain continence (36), making it more difficult to relax on demand. Halski et al. (37) observed higher tonic PFM activity when the hips were flexed compared to when the hips were extended in a group of post-menopausal women. They recorded rest data during five-second intervals between maximal voluntary PFM contraction repetitions. Participants may not have been able to completely relax their PFMs in the short time interval between voluntary contractions (37). When treatment aims to reduce tonic activity, patients may benefit from sufficient time and adequate instruction to facilitate relaxation.

Hip rotation may influence PFM length and tension due to the shared fascial connection between the obturator internus muscle and the pubococcygeus/iliococcygeus portion of the levator ani muscles (29, 44). The PFMs also have a high density of connective tissue compared to other skeletal muscles, making them responsive to the movement of tissues around them (44). The obturator internus muscles lengthen when the hips rotate medially, influencing the tension and anchor point of the PFMs. Likewise, when the obturator internus contracts isometrically to stabilize the hip in lateral rotation, the tension in the obturator muscle may contribute to the stability of the PFM attachment. As anticipated, PFM tonic activation was facilitated with hip medial rotation while the hips were flexed and extended, but only in continent participants. Lengthening of the

obturator internus muscle may have increased tension in the PFMs, generating muscle spindle activity that increased excitation of the motoneuronal pool of the PFMs, consequently increasing tonic activation.

Tonic activation was also facilitated by hip medial and lateral rotation in participants with mild symptoms of SUI. Women with mild symptoms may mitigate leakage through heightened PFM activation in response to hip rotation or other perturbations. Women with mild SUI may instinctively initiate a guarding response when moved out of a neutral position. There is evidence that hip rotation range of motion is compromised in some women with SUI (45) and alterations in pelvic connective tissues have been identified in women with SUI (46-48). There could be less influence of hip rotation on the length of the obturator internus muscle which could negate the ability of hip rotation to influence PFM activation in women with strained pelvic floor tissues. Among those with moderate SUI, such damage may have hampered the ability of hip rotation to alter tonic activation.

I hypothesized that hip flexion and rotation would affect maximum voluntary activation of the PFMs because of the influence of the length and tension of the abdominal and obturator internus muscles, respectively. I suspect that tension across the pelvic diaphragm partially depends on hip position. These could influence contractility and afferent sensory information driving voluntary activation. Activation patterns differed between symptomatic and asymptomatic cohorts when voluntary PFM contractions were performed across hip positions (Table 4.3). In the group of women who were continent, maximum PFM activity was significantly higher when the hips were extended compared to flexed and when lateral rotation was sustained in the tabletop pose

compared to no rotation (Table 4.3). Arguably, in women with intact neuromuscular structures, these two positions can tension and stabilize the PFMs where activation is facilitated. While other researchers have investigated the effect of lumbopelvic posture on PFM activation (19-21, 49, 50), this study and another by Halski et al. (37) are the only ones to examine the effect of hip flexion on PFM activation. Both found higher maximum activation when the hips were extended than when flexed.

When rotating the hips while they are extended, there is minimal to no hip abduction and a limited amount of hip rotation possible. In contrast, rotating the hips in the tabletop pose requires the hips to adduct to achieve medial rotation. Therefore, the influence of rotation on the PFMs will be different when the hips are flexed and extended. Although a significant change in maximum PFM activity was detected in the two groups of women with SUI, the pattern was unclear. Hip flexion did not influence maximum activation in the SUI cohorts. Evidence in the symptomatic cohorts suggests that moving from neutral to medial rotation lowers maximal PFM activation in the symptomatic participants, regardless of hip flexion position. These findings are likely due to structural (reduced muscle mass, laxity to supporting structures) and functional (altered motor control) changes observed in women with SUI. Hip rotation may inhibit muscle substitution strategies typically used to enhance PFM activation (adductor, gluteal recruitment). If tissue strain were present in participants with SUI, altering hip position may not alter length or tension enough to facilitate activation, as seen in the women without SUI.

Limitations

In this study, the volunteers in the different study groups were not matched for age, BMI, or parity; continent participants were younger (29.8 ± 13.5 years) than those with mild (46.1 ± 14.4 years) and moderate SUI (46.0 ± 10.4 years) and had lower parity compared to both groups of participants with SUI. These differences are not surprising given that higher age (51) and parity (52) have been associated with higher prevalence of urinary incontinence. It is unclear what effect age has on PFM morphology, function, and activation, as many confounding factors exist. Given that participants with mild SUI were older and had higher parity than continent participants, yet they generated similar EMG amplitudes, age and parity are unlikely to be a substantive cause of differences in PFM activation observed in this study (53). In addition, it has recently been suggested that, unlike other skeletal muscles, PFM cross-sectional area (CSA) and muscle volume are preserved with increasing age (54). Aging has a negligible effect on resting vaginal closure force (55).

While the sample size of this study was a small convenience sample, appropriate non-parametric statistical tests were used, and the results cannot be generalized to the population. Where significant findings were detected, effect sizes were presented to estimate the magnitude of the effect in the general population. Indeed, altered hip position influenced PFM activation, and differences between women with and without SUI were detected. Other quality studies examining the relationship between PFM activation and various conditions (response to perturbations, challenges to balance, altered postures) have also recruited small numbers and were able to make important contributions to our knowledge and understanding of PFM function (19, 26, 27, 35, 36, 56).

A strength of the study is the use of the DSE, which was designed to record activation from a consistent location over the PFMs with appropriately sized and spaced detection surfaces for this application. The DSE remained in position through multiple position changes in all participants, was comfortable for the participant, and could detect small changes in PFM activation. Vaginal probes are also convenient, easy to use, and accepted by participants, and have been used in many investigations to describe PFM function across various conditions (19, 34, 38, 57). However, electrodes mounted on probes can move within the vaginal canal during position changes and in response to gravitational loading, which could impact findings. In addition, the detection surfaces on vaginal probes are often quite large relative to the size of the PFMs, which could contribute to unwanted crosstalk from nearby muscles, contaminating the signal. Appropriately sized detection surfaces are critical when considering the deep muscles of the hip and abdomen.

While tonic PFM activation amplitude has been reported to be influenced by bladder fullness (34, 58, 59), which may have affected the results of other studies, it is unlikely that the state of bladder filling influenced the results of the present study. All women were required to empty their bladder just before data collection, and the order of the positions was randomized.

Conclusions

Hip position is important in evaluating the capacity of women to activate their PFMs maximally, but the effect depends on continence status. The findings of this study suggest that the position of the hips will influence PFM activation, moderating both phasic recruitment and basal tone. Indeed, to optimally relax the PFMs, flexing the hips

to 90 degrees and resting the lower legs on a flat surface is recommended. This strategy may be relevant for women with dyspareunia or to reduce excess tension while performing a speculum examination. Altering hip positions may enhance voluntary PFM activation and be useful for initial training or exercise progression. Hip rotation position may also be used functionally to enhance continence control, yet this effect requires further investigation.

This is the first study to investigate the effect of hip position on PFM activation. Women with and without SUI demonstrated differences in the influence of hip flexion and hip rotation positions on tonic activation amplitudes recorded from the PFMs. In contrast, the relationship between hip position and maximal activation is less clear. While the effects of altering hip position are variable depending on continence status, hip position must be considered when evaluating PFM strength and tone, as well as recommending positions in which to relax or exercise the PFMs. Further work is required to identify how changes in tonic activation and maximal activation capacity based on hip position might influence urethral and bladder neck support and urethral closure pressure.

4.6 References

1. DeLancey JO. Stress urinary incontinence: where are we now, where should we go? Am J Obstet Gynecol. 1996;175(2):311-9.

2. Haylen BT, de Ridder D, Freeman RM, Swift SE, Berghmans B, Lee J, et al. An International Urogynecological Association (IUGA)/International Continence Society (ICS) joint report on the terminology for female pelvic floor dysfunction. Neurourol Urodyn. 2010;29(1):4-20.

3. Ashton-Miller JA, DeLancey JO. Functional anatomy of the female pelvic floor. Ann N Y Acad Sci. 2007;1101:266-96.

4. Bo K, Stien R. Needle EMG registration of striated urethral wall and pelvic floor muscle activity patterns during cough, Valsalva, abdominal, hip adductor, and gluteal muscle contractions in nulliparous healthy females. Neurourol Urodyn. 1994;13(1):35-41.

5. Sapsford RR, Hodges PW, Richardson CA, Cooper DH, Markwell SJ, Jull GA. Co-activation of the abdominal and pelvic floor muscles during voluntary exercises. Neurourol Urodyn. 2001;20(1):31-42.

6. Jordre B, Schweinle W. Comparing resisted hip rotation with pelvic floor muscle training in women with stress urinary incontinence: A pilot study. Journal of Women's Health Physical Therapy. 2014;38(2):81-9.

7. Madill SJ, McLean L. Quantification of abdominal and pelvic floor muscle synergies in response to voluntary pelvic floor muscle contractions. J Electromyogr Kinesiol. 2008;18(6):955-64.

8. Tuttle LJ, DeLozier ER, Harter KA, Johnson SA, Plotts CN, Swartz JL. The Role of the Obturator Internus Muscle in Pelvic Floor Function. Journal of Women’s Health Physical Therapy. 2016;40(1):15-9.

9. Sapsford RR, Hodges PW. Contraction of the pelvic floor muscles during abdominal maneuvers. Arch Phys Med Rehabil. 2001;82(8):1081-8.

10. Sapsford R. Rehabilitation of pelvic floor muscles utilizing trunk stabilization. Man Ther. 2004;9(1):3-12.

11. Tuttle LJ, Autry T, Kemp C, Lassaga-Bishop M, Mettenleiter M, Shetter H, et al. Hip exercises improve intravaginal squeeze pressure in older women. Physiother Theory Pract. 2020;36(12):1340-7.

12. Hwang UJ, Lee MS, Jung SH, Ahn SH, Kwon OY. Relationship Between Sexual Function and Pelvic Floor and Hip Muscle Strength in Women With Stress Urinary Incontinence. Sex Med. 2021;9(2):100325.

13. Marques SAA, Silveira S, Passaro AC, Haddad JM, Baracat EC, Ferreira EAG. Effect of Pelvic Floor and Hip Muscle Strengthening in the Treatment of Stress Urinary Incontinence: A Randomized Clinical Trial. J Manipulative Physiol Ther. 2020;43(3):247-56.

14. Underwood DB, Calteaux TH, Cranston AR, Novotny SA, Hollman JH. Hip and pelvic floor muscle strength in women with and without stress urinary incontinence: A ccase-control study. Journal of Women's Health Physical Therapy. 2012;36(1):55-61.

15. Baba T, Homma Y, Takazawa N, Kobayashi H, Matsumoto M, Aritomi K, et al. Is urinary incontinence the hidden secret complications after total hip arthroplasty? Eur J Orthop Surg Traumatol. 2014;24(8):1455-60.

16. Tamaki T, Oinuma K, Shiratsuchi H, Akita K, Iida S. Hip dysfunction-related urinary incontinence: a prospective analysis of 189 female patients undergoing total hip arthroplasty. Int J Urol. 2014;21(7):729-31.

17. Okumura K, Yamaguchi K, Tamaki T, Oinuma K, Tomoe H, Akita K. Prospective analyses of female urinary incontinence symptoms following total hip arthroplasty. Int Urogynecol J. 2017;28(4):561-8.

18. Bo K, Finckenhagen HB. Is there any difference in measurement of pelvic floor muscle strength in supine and standing position? Acta Obstet Gynecol Scand. 2003;82(12):1120-4.

19. Capson AC, Nashed J, McLean L. The role of lumbopelvic posture in pelvic floor muscle activation in continent women. J Electromyogr Kinesiol. 2011;21(1):166-77.

20. Chen CH, Huang MH, Chen TW, Weng MC, Lee CL, Wang GJ. Relationship between ankle position and pelvic floor muscle activity in female stress urinary incontinence. Urology. 2005;66(2):288-92.

21. Chen HL, Lin YC, Chien WJ, Huang WC, Lin HY, Chen PL. The effect of ankle position on pelvic floor muscle contraction activity in women. J Urol. 2009;181(3):1217-23.

22. Frawley HC, Galea MP, Phillips BA, Sherburn M, Bo K. Effect of test position on pelvic floor muscle assessment. Int Urogynecol J Pelvic Floor Dysfunct. 2006;17(4):365-71.

23. Leitner M, Moser H, Taeymans J, Kuhn A, Radlinger L. Pelvic floor muscle displacement during voluntary and involuntary activation in continent and incontinent women: a systematic review. Int Urogynecol J. 2015;26(11):1587-98.

24. Morgan DM, Kaur G, Hsu Y, Fenner DE, Guire K, Miller J, et al. Does vaginal closure force differ in the supine and standing positions? Am J Obstet Gynecol. 2005;192(5):1722-8.

25. Ptaszkowski K, Zdrojowy R, Slupska L, Bartnicki J, Dembowski J, Halski T, et al. Assessment of bioelectrical activity of pelvic floor muscles depending on the orientation of the pelvis in menopausal women with symptoms of stress urinary incontinence: continued observational study. Eur J Phys Rehabil Med. 2017;53(4):564-74.

26. Sapsford RR, Richardson CA, Maher CF, Hodges PW. Pelvic floor muscle activity in different sitting postures in continent and incontinent women. Arch Phys Med Rehabil. 2008;89(9):1741-7.

27. Sapsford RR, Richardson CA, Stanton WR. Sitting posture affects pelvic floor muscle activity in parous women: an observational study. Aust J Physiother. 2006;52(3):219-22.

28. Norton PA, Baker JE. Postural changes can reduce leakage in women with stress urinary incontinence. Obstet Gynecol. 1994;84(5):770-4.

29. Muro S, Nimura A, Ibara T, Chikazawa K, Nakazawa M, Akita K. Anatomical basis for contribution of hip joint motion by the obturator internus to defaecation/urinary functions by the levator ani via the obturator fascia. J Anat. 2023;242(4):657-65.

30. Gray H. Gray's Anatomy 37th ed. Edinburgh: Churchill Livingstone; 1989.

31. Agur AMR, Dalley AF. Grant's atlas of anatomy. Edition 14. ed. Philadelphia: Wolters Kluwer; 2017. xviii, 867 pages p.

32. Lee YC, Callary SA, Howie DW, Thewlis D, Solomon LB. The effect of hip position on the length of trochanteric muscles: potential implications for early postoperative management of hip arthroplasty. J Arthroplasty. 2012;27(6):953-60 e1-2.

33. Burti JS, Hacad CR, Zambon JP, Polessi EA, Almeida FG. Is there any difference in pelvic floor muscles performance between continent and incontinent women? Neurourol Urodyn. 2015;34(6):544-8.

34. Smith MD, Coppieters MW, Hodges PW. Postural activity of the pelvic floor muscles is delayed during rapid arm movements in women with stress urinary incontinence. Int Urogynecol J Pelvic Floor Dysfunct. 2007;18(8):901-11.

35. Thompson JA, O'Sullivan PB, Briffa NK, Neumann P. Altered muscle activation patterns in symptomatic women during pelvic floor muscle contraction and Valsalva manouevre. Neurourol Urodyn. 2006;25(3):268-76.

36. Smith MD, Coppieters MW, Hodges PW. Postural response of the pelvic floor and abdominal muscles in women with and without incontinence. Neurourol Urodyn. 2007;26(3):377-85.

37. Halski T, Ptaszkowski K, Slupska L, Dymarek R, Paprocka-Borowicz M. Relationship between lower limb position and pelvic floor muscle surface electromyography activity in menopausal women: a prospective observational study. Clin Interv Aging. 2017;12:75-83.

38. Madill SJ, Harvey MA, McLean L. Women with SUI demonstrate motor control differences during voluntary pelvic floor muscle contractions. Int Urogynecol J Pelvic Floor Dysfunct. 2009;20(4):447-59.

39. Devreese A, Staes F, De Weerdt W, Feys H, Van Assche A, Penninckx F, et al. Clinical evaluation of pelvic floor muscle function in continent and incontinent women. Neurourol Urodyn. 2004;23(3):190-7.

40. Deindl FM, Vodusek DB, Hesse U, Schussler B. Pelvic floor activity patterns: comparison of nulliparous continent and parous urinary stress incontinent women. A kinesiological EMG study. Br J Urol. 1994;73(4):413-7.

41. Morkved S, Salvesen KA, Bo K, Eik-Nes S. Pelvic floor muscle strength and thickness in continent and incontinent nulliparous pregnant women. Int Urogynecol J Pelvic Floor Dysfunct. 2004;15(6):384-9; discussion 90.

42. Morin M, Bourbonnais D, Gravel D, Dumoulin C, Lemieux MC. Pelvic floor muscle function in continent and stress urinary incontinent women using dynamometric measurements. Neurourol Urodyn. 2004;23(7):668-74.

43. Tosun OC, Dayican DK, Keser I, Kurt S, Yildirim M, Tosun G. Are clinically recommended pelvic floor muscle relaxation positions really efficient for muscle relaxation? Int Urogynecol J. 2022.

44. Tuttle LJ, Nguyen OT, Cook MS, Alperin M, Shah SB, Ward SR, et al. Architectural design of the pelvic floor is consistent with muscle functional subspecialization. Int Urogynecol J. 2014;25(2):205-12.

45. Hartigan E, McAuley JA, Lawrence M, Keafer C, Ball A, Michaud A, et al. Pelvic Floor Muscle Performance, Hip Mobility, and Hip Strength in Women With and Without Self-Reported Stress Urinary Incontinence. The Journal of Women's & Pelvic Health Physical Therapy. 2019;43(4):160-70.

46. Cör A, Barbič M, Kralj B. Differences in the quantity of elastic fibres and collagen type I and type III in endopelvic fascia between women with stress urinary incontinence and controls. Urological Research. 2003;31(2):61-5.

47. Ulmsten U, Ekman G, Giertz G, Malmstrom A. Different biochemical composition of connective tissue in continent and stress incontinent women. Acta Obstet Gynecol Scand. 1987;66(5):455-7.

48. Ulmsten U, Falconer C. Connective tissue in female urinary incontinence. Curr Opin Obstet Gynecol. 1999;11(5):509-15.

49. Lee K. Activation of Pelvic Floor Muscle During Ankle Posture Change on the Basis of a Three-Dimensional Motion Analysis System. Med Sci Monit. 2018;24:7223-30.

50. Cerruto MA, Vedovi E, Mantovani W, D'Elia C, Artibani W. Effects of ankle position on pelvic floor muscle electromyographic activity in female stress urinary incontinence: preliminary results from a pilot study. Arch Ital Urol Androl. 2012;84(4):184-8.

51. Hannestad YS, Rortveit G, Sandvik H, Hunskaar S, Norwegian EsEoIitCoN-T. A community-based epidemiological survey of female urinary incontinence: the Norwegian EPINCONT study. Epidemiology of Incontinence in the County of Nord-Trondelag. J Clin Epidemiol. 2000;53(11):1150-7.

52. Rortveit G, Hannestad YS, Daltveit AK, Hunskaar S. Age- and type-dependent effects of parity on urinary incontinence: the Norwegian EPINCONT study. Obstet Gynecol. 2001;98(6):1004-10.

53. Aukee P, Penttinen J, Airaksinen O. The effect of aging on the electromyographic activity of pelvic floor muscles. A comparative study among stress incontinent patients and asymptomatic women. Maturitas. 2003;44(4):253-7.

54. Morris VC, Murray MP, Delancey JO, Ashton-Miller JA. A comparison of the effect of age on levator ani and obturator internus muscle cross-sectional areas and volumes in nulliparous women. Neurourol Urodyn. 2012;31(4):481-6.

55. Trowbridge ER, Wei JT, Fenner DE, Ashton-Miller JA, Delancey JO. Effects of aging on lower urinary tract and pelvic floor function in nulliparous women. Obstet Gynecol. 2007;109(3):715-20.

56. Smith MD, Coppieters MW, Hodges PW. Is balance different in women with and without stress urinary incontinence? Neurourol Urodyn. 2008;27(1):71-8.

57. Thompson JA, O'Sullivan PB, Briffa NK, Neumann P. Differences in muscle activation patterns during pelvic floor muscle contraction and Valsalva maneuver. Neurourol Urodyn. 2006;25(2):148-55.

58. Deindl FM, Vodusek DB, Hesse U, Schussler B. Activity patterns of pubococcygeal muscles in nulliparous continent women. Br J Urol. 1993;72(1):46-51.

59. McLean L, Normandeau C, Hodder J. The impact of state of bladder fullness on tonic and phasic activation of the pelvic floor muscles in women. J Electromyogr Kinesiol. 2016;27:60-5.

Chapter 5

Pelvic floor muscle awareness is lower among women with stress urinary incontinence compared to women without stress urinary incontinence

5.1 Abstract

The aims of this study were to compare pelvic floor muscle (PFM) awareness among women with and without stress urinary incontinence (SUI), to describe the relationship between activation of the PFMs and PFM awareness, and to explore whether PFM awareness is altered when voluntary contractions are performed in different positions. An observational cohort study design was used. Participants with and without SUI were recruited from the local community. In a single laboratory visit, participants performed PFM contractions while assuming different lumbopelvic and hip rotation positions while electromyographic (EMG) signals were recorded from the PFMs using Differential Suction Electrodes (DSEs). After each PFM contraction, participants rated their perceived awareness of the PFM contraction using a visual analog scale (VAS). Women with SUI were divided into two groups based on incontinence severity as determined using a validated questionnaire. Spearman's Rho was used to evaluate the relationship between EMG activity and PFM awareness. The Kruskal-Wallis test was used to determine the effect of continence status on perceived PFM awareness. Friedman's two-way analysis of variance by ranks test was used to determine the effect of altered position on PFM awareness. An alpha of 0.05 was used for all statistical tests. Thirty-one participants completed the study protocol and were assigned to three cohorts:

women who were continent (n = 12), women with mild SUI (n = 9), and women with moderate SUI (n = 10). In the lying positions, significant positive correlations between PFM awareness and PFM activation were identified in women without SUI but not in women with SUI. In standing, the relationship between PFM awareness and EMG activity of the PFMs was negative for all participants. Participants who were continent rated their PFM awareness higher than those with mild SUI, and in some positions higher than those with moderate SUI. PFM awareness values were consistently higher in supine compared to standing among all participants, and a significant effect of position on PFM awareness was found. This preliminary study is the first to quantify perceived PFM awareness of activation and compare it to actual EMG activation. These findings suggest that not all women who report "feeling" their PFMs contract are indeed perceiving a correct PFM contraction, particularly among those with SUI. A palpation exam or other feedback approach is required to confirm proper PFM recruitment. Also, PFM awareness can be influenced by altering lumbopelvic and hip rotation positions. The implication of deficits in PFM awareness on motor control of the PFMs warrants further investigation, particularly as it relates to urinary continence.

5.2 Introduction

When bladder pressure exceeds urethral closure pressure, urine leakage can result. Stress urinary incontinence (SUI) is the involuntary leaking of urine when it occurs in conjunction with a sudden rise in intra-abdominal pressure during activities such as laughing, coughing, sneezing, jumping, and running (1). Although not always (2, 3), the pelvic floor muscles (PFMs) are thought to be implicated in SUI (4). Conservative

management of SUI with pelvic floor muscle training (PFMT) has been shown to reduce and, in many cases, alleviate urine leakage (5).

Motor control impairments have been identified in women with SUI, including absent feedforward activation during low-load tasks (6), absent pre-contraction of the PFMs prior to a rise in intra-abdominal pressure (7), and the use of substitution strategies or compensations such as bracing, activating the hip adductors, contracting the gluteus muscles, and/or engaging the abdominal muscles (8). It has been suggested that postural correction and proprioceptive acuity may be compromised in women with SUI because of these altered motor control patterns (9, 10). Sensory information contributes to motor learning, and loss of proprioceptive afferents has been shown to affect muscle strength and muscle tone and to disrupt postural reflexes, leading to impairments in spatial and temporal aspects of volitional movement (11). Trauma to the tissues (neuromuscular, fascial, and connective tissues) within the pelvic floor during vaginal childbirth and age-related nerve degeneration are thought to contribute to pelvic floor dysfunction (12, 13). The motor and sensory nerves that supply the pelvic floor follow a common pathway. When the motor nerve is disrupted, such as during vaginal childbirth (14), it is very likely that the sensory nerve is also disrupted. In a recent narrative review on proprioception in SUI by Kharaju et al. (15), the authors pointed to a need for further research in the area of proprioception and its relationship to SUI.

When learning to contract the PFMs for the first time or re-educating the PFMs following a trauma such as childbirth or genitopelvic surgery, women rely on sensory feedback to adjust their motor patterns as appropriate. To date, few reports have addressed the concept of pelvic floor muscle (PFM) awareness. Thompson et al. (8) and

Devreese et al. (7) both reported preliminary evidence of impaired accuracy of awareness of a pelvic floor contraction in those with SUI. More recently, Uechi et al. (16) sought to quantify PFM awareness and compare perceived awareness of PFM strength with PFM strength measured using digital palpation and the 6-point Modified Oxford Scale (MOS). Only 33% (n = 82) of the women demonstrated an accurate self-perception of the PFMs contracting, suggesting a discrepancy between measured PFM strength and the perception of the PFMs contracting. Yet these findings should be interpreted with caution as the act of performing the PFM manual muscle test may have had an impact on awareness through the additional tactile feedback provided during the assessment (17). PFM awareness has yet to be evaluated against force or electromyographic (EMG) activation. Further, there is evidence that PFM contractile characteristics such as strength (18), PFM excursion (18, 19), and electrical activation (20-22) are influenced by body position, yet the peer-reviewed literature does not include any formal attempt to describe how different positions may affect perceived PFM awareness or the accuracy of this awareness.

Differences in PFM awareness between women with and without SUI have not been reported in the literature as a primary outcome, and the effect of altering body position on PFM awareness during voluntary contraction has not been studied. As such, this study was designed to explore the relationship between perception of task performance and actual task performance when women with and without SUI perform maximal effort voluntary PFM contractions. The specific aims of this study were to compare perceived PFM awareness among continent women and women with mild and moderate SUI, to investigate the relationship between PFM awareness and activation of the PFMs when women perform maximal effort voluntary contractions, and to investigate

whether PFM awareness changes when contractions are performed in different body positions.

5.3 Methods

This exploratory study was completed on a subset of the participants described in Chapters 3 and 4. Participant recruitment and screening, collection of demographic data, instrumentation, data acquisition and reduction are described in detail in Chapter 3 (3.3 Methods).

5.3.1 PFM Awareness

Immediately after completing each PFM MVC in the protocol, participants were instructed to rate their awareness of the PFM contraction on a 100 mm horizontal visual analog scale (VAS). The anchors at the far left (VAS = 0) of the 100 mm line indicated the participant did not feel the PFM contraction whatsoever, using the descriptor "does not feel at all." The far-right anchor (VAS = 100) indicated that the participant felt the PFMs contracting firmly using the descriptor "feels the most." Immediately after performing the PFM contraction, participants drew a perpendicular line through the 100 mm line to indicate how much they “felt” their PFMs contracting during each PFM MVC effort in each of the positions, where a higher VAS score indicated greater awareness of the PFM contracting. A standard ruler was used to measure the distance from the left anchor of the line to the participants' perpendicular line, indicating how much a given participant was aware of each PFM contraction. Measurements were recorded in millimeters (mm) but reported in centimeters (cm).

5.3.2 Description of lumbopelvic and hip rotation positions

Variations in lumbopelvic postures were assumed in lying and standing as described in Chapter 3 (Figure 3.2). Hip rotation positions included hip medial and lateral rotation compared to no rotation while lying with the hips and knees extended (Figure 4.1). Hip flexion and hip extension positions can be viewed in Figure 4.2A.

5.3.3 Statistical Analysis

The statistical analysis procedures are described in Chapter 3 (3.3.7 Statistical Analysis). Analysis of the PFM sensory awareness data is described below.

The Kruskal-Wallis test was used to detect group differences (no SUI, mild SUI, moderate SUI) in sensory awareness. Where significant group main effects were identified, post-hoc testing was performed using the Mann-Whitney U test. The relationship between sensory awareness and PFM activity was analyzed by computing Spearman's Rho correlation coefficients for each group in the eight positions. Finally, the effect of position on perceived PFM awareness was determined independently for each group where Friedman's two-way analysis of variance by ranks test was used to examine the effect of altered position (i. standing lumbopelvic position, ii. lying lumbopelvic position, and iii. lying hip rotation) on sensory awareness. Where significant position effects were found, the Wilcoxon Signed-Ranks test was used to examine pairwise differences in perceived awareness.

Effect sizes were computed (*r*-value) and described using the following interpretation (no effect $r < 0.10$, small $0.10 \leq r < 0.23$, moderate $0.24 \leq r < -0.36$, and large $r \geq 0.37$) (23). Alpha (α) was set *a priori* at $\alpha = 0.05$ and was adjusted to account for

multiple comparisons using a Bonferroni correction. Findings were described as a trend when $p \leq 2\alpha$.

5.4 Results

5.4.1 Subject demographics

Based on observations during the initial data collection sessions, my research team and I began to record sensory awareness data using VASs after data collection described in Chapter 3 was already underway. Sensory awareness data and PFM activation data were analyzed from 31 eligible participants. As such, the demographic information presented in Table 5.1 represents a subset of the sample described in Chapter 3 (3.4.1 Participant demographics). While there were no significant group differences in age, BMI, PFM strength, or PFM tone, women with mild ($p = 0.009$) and moderate SUI ($p = 0.013$) had higher parity than women without SUI.

Table 5.1 Participant demographic information

Demographic	Group Median (IQR)			
	Continent (n = 12)	**Mild SUI (n = 9)**	**Moderate SUI (n = 10)**	Kruskal-Wallis
Age (years)	25.0 (21.0)	52.0 (24.5)	45.5 (11.0)	$H = 4.80$, $p = 0.090$
BMI (kg/m^2)	22.6 (5.2)	22.8 (5.4)	25.9 (8.9)	$H = 5.24$, p = 0.073
Parity	0 (0.8)[a]	2 (1.5)[b]	1.5 (2.3)[b]	***H* = 8.92, *p* = 0.012***
IIQ-7	0.0 (0.0)[a]	4.8 (16.8)[b]	23.9 (12.2)[c]	***H* = 23.26, *p* < 0.001***
UDI-6	0.0 (0.0) [a]	11.8 (7.0) [b]	34.7 (15.4) [c]	***H* = 27.17, *p* < 0.001***
ICIQ-UI SF	0.0 (0.0) [a]	4.0 (2.0) [b]	7.5 (5.3) [c]	***H* = 28.31, *p* < 0.001***
PFM Strength	4.0 (1.0)	4.0 (1.0)	4.0 (1.3)	$H = 3.06$, $p = 0.216$
PFM Tone	0.5 (1.0)	0.5 (1.25)	0 (1.6)	$H = 1.86$, $p = 0.394$

* indicates a significant group effect was detected using the Kruskal-Wallis test, and superscripts a,b, and/or c ([a,b,c]) indicate group differences were detected using the Mann-Whitney U test with alpha adjusted to $\alpha \leq 0.017$. SUI (stress urinary incontinence); IQR (interquartile range), BMI (body mass index), IIQ-7 (Incontinence Impact Questionnaire-7), UDI-6 (Urogenital Distress Inventory-6), ICIQ-UI SF (International Consultation on Incontinence Questionnaire Short Form), PFM (pelvic floor muscle).

5.4.2 PFM awareness and continence status

Perceived awareness of the PFMs during voluntary contractions differed between cohorts across positions (Table 5.2). When assuming a crook-lying posture where lumbopelvic posture was neutral, continent participants rated PFM awareness the highest, followed by participants with moderate SUI, and those with mild SUI rated their awareness the lowest. Similar patterns were observed in the hypolordotic and hyperlordotic postures, although not all differences reached significance (Table 5.2). In all three standing positions, continent women rated PFM awareness higher than those with mild SUI, where the effect size was moderate to large (Table 5.2). PFM awareness was not different between women with mild and moderate SUI or between continent participants and participants with moderate SUI (Table 5.2). PFM awareness values were also higher in continent women compared to those with mild SUI when the hips were

held in medial rotation and higher in continent women compared to both mild and moderate SUI groups in lateral rotation (Table 5.2). The effect size was deemed to be moderate to large (Table 5.2). A trend was detected ($p = 0.018$) such that continent women rated PFM awareness higher compared to those with mild SUI when in the neutral hip rotation posture where the effect size was moderate ($r = 0.30$) (Table 5.2).

Table 5.2 PFM awareness in different positions

	Effect of Continence Status on PFM Awareness: Group Main Effect				Pairwise Differences		
groups	Continent (n=12)	Mild SUI (n=10)	Moderate SUI (n=9)	*Kruskal Wallis Test*		*Mann-Whitney*	
Lying lumbopelvic				*Group main effect (α = 0.05)*	*Pairs*	*p-value (α = 0.17)*	*Effect size (r)*
Crook-lying (Neutral)							
VAS Median (IQR) cm	8.1 (1.0)	5.7 (2.0)	7.5 (2.1)	***H(2)* = 21.52, *p* < 0.001***	Cont Mild	***p* < 0.001***	*r* = 0.55
Mean rank	60.9	29.0	46.5		Cont Mod	***p* = 0.017***	*r* = 0.29
					Mild Mod	***p* = 0.006***	*r* = 0.36
Supine (Hyperlordosis)							
VAS Median (IQR) cm	7.4 (2.3)	6.5 (2.2)	7.1 (3.5)	*H(2)* = 5.84, *p* = 0.054‡	Cont Mild	*p* = 0.018‡	*r* = 0.30
Mean rank	54.5	38.0	46.0		Cont Mod	*p* = 0.189	*r* = 0.16
					Mild Mod	*p* = 0.246	*r* = 0.15
Table-top (Hypolordosis)							
VAS Median (IQR) cm	7.8 (1.8)	54 (2.6)	7.5 (1.2)	***H(2)* = 19.89, *p* < 0.001***	Cont Mild	***p* < 0.001***	*r* = 0.52
Mean rank	60.4	29.8	46.4		Cont Mod	*p* = 0.018‡	*r* = 0.29
					Mild Mod	***p* = 0.008***	*r* = 0.35
Standing Lumbopelvic							
Neutral							
VAS Median (IQR) cm	6.8 (2.4)	6.0 (1.8)	5.8 (2.6)	***H(2)* = 7.05, *p* = 0.029**	Cont Mild	***p* = 0.014***	*r* = 0.31
Mean rank	56.1	39.1	43.3		Cont Mod	*p* = 0.052	*r* = 0.24
					Mild Mod	*p* = 0.517	*r* = 0.09
Hyperlordosis							
VAS Median (IQR) cm	6.5 (2.3)	5.1 (3.9)	4.6 (3.3)	***H(2)* = 8.73, *p* = 0.013***	Cont Mild	***p* = 0.009***	*r* = 0.33
Mean rank	57.4	39.6	41.2		Cont Mod	***p* = 0.017***	*r* = 0.29
					Mild Mod	*p* = 0.879	*r* = 0.02
Hypolordosis							
VAS Median (IQR) cm	6.9 (2.8)	4.3 (4.1)	6.6 (3.5)	***H(2)* = 11.08, *p* = 0.004***	Cont Mild	***p* = 0.001***	*r* = 0.43
Mean rank	57.1	34.1	46.5		Cont Mod	*p* = 0.124	*r* = 0.19
					Mild Mod	*p* = 0.095	*r* = 0.22
Lying Hip Positions							
No Rotation				*H(2)* = 5.84, *p* = 0.054‡	Cont Mild	*p* = 0.018‡	*r* = 0.30
VAS Median (IQR) cm	7.4 (2.3)	6.5 (2.2)	7.1 (3.5)		Cont Mod	*p* = 0.189	*r* = 0.16
Mean rank	54.5	38.0	46.0		Mild Mod	*p* = 0.246	*r* = 0.15
Medial Rotation				***H(2)* = 9.225, *p* = 0.010***	Cont Mild	***p* = 0.003***	*r* = 0.38
VAS Median (IQR) cm	7.9 (2.3)	4.9 (2.4)	5.8 (4.3)		Cont Mod	*p* = 0.046	*r* = 0.25
Mean rank	57.3	37.3	43.4		Mild Mod	*p* = 0.452	*r* = 0.10
Lateral Rotation				***H(2)* = 19.998, *p* < 0.001***	Cont Mild	***p* < 0.001***	*r* = 0.59
VAS Median (IQR) cm	76 (1.5)	60 (0.6)	6.2 (3.0)		Cont Mod	***p* = 0.011***	*r* = 0.31
Mean rank	61.3	31.9	41.8		Mild Mod	*p* = 0.349	*r* = 0.13

PFM pelvic floor muscle; SUI stress urinary incontinence; VAS visual analog scale; IQR interquartile range. Cont group without SUI; Mod SUI group with moderate SUI.

5.4.3 The relationship between PFM awareness and PFM activation

In continent women, moderate to large positive correlations were detected between PFM awareness and activation across all the recumbent positions where lumbopelvic posture and hip rotation were altered (Table 5.3). A positive correlation between PFM awareness and activation was observed in women with moderate SUI but only with the lumbar spine in the neutral posture while assuming a crook-lying position. In standing, the correlation between PFM awareness and activation was negative for all groups, where higher values of PFM EMG activity were associated with lower reported PFM awareness. The negative relationship was significant in continent participants and in those with mild SUI in the standing hypolordosis posture, only reaching significance in the mild SUI group when participants assumed the neutral spine posture (Table 5.3).

Table 5.3 The relationship between PFM awareness and activation

Postures	**Spearman's Correlation Coefficients and *p*-value by Group**		
	Continent (n=12)	**Mild SUI** (n=10)	**Moderate SUI** (n=9)
Lying with lumbopelvic posture altered			
Supine^	***ρ* = 0.546, *p* < 0.001***	ρ = 0.068, p = 0.735	ρ = 0.087, p = 0.647
Crook-lying	***ρ* = 0.342, *p* = 0.041***	ρ = 0.054, p = 0.787	***ρ* = 0.414, *p* = 0.023***
Tabletop	***ρ* = 0.351, *p* = 0.035***	ρ = 0.088, p = 0.664	ρ = -0.095, p = 0.616
Lying with hip rotation altered			
Neutral^	***ρ* = 0.546, *p* < 0.001***	ρ = 0.068, p = 0.735	ρ = 0.087, p = 0.647
Lateral Rotation	***ρ* = 0.522, *p* = 0.001***	ρ = 0.016, p = 0.937	ρ = -0.003, p = 0.987
Medial Rotation	***ρ* = 0.477, *p* = 0.003***	ρ = 0.001, p = 0.999	ρ = 0.153, p = 0.418
Standing with lumbopelvic posture altered			
Neutral	***ρ* =** -0.277, p = 0.102	***ρ* = -0.479, *p* = 0.011***	ρ = -0.086, p = 0.650
Hypolordosis	***ρ* = -0.558, *p* < 0.001***	***ρ* = -0.599, *p* < 0.001***	ρ = -0.045, p = 0.813
Hyperlordosis	***ρ* =** -0.316, p = 0.060‡	ρ = -0.215, p = 0.282	ρ = -0.067, p = 0.725

*indicates correlation was statically significant; ‡ indicates a trend; ^ same posture (lying supine with legs extended and hips in a neutral position)

5.4.4 The effect of position on perceived PFM awareness

PFM awareness was influenced by assuming different positions where the effect of lumbopelvic and hip rotation position on PFM awareness appeared to be inconsistent across the three groups, except for when all participants moved from lying down to standing; PFM awareness was perceived to be greater while performing PFM contractions lying down compared to when they were performed in standing (Table 5.4). The effect size was large in continent women (r = 0.59) and in women with moderate SUI (r = 0.40), while the effect size was moderate in those with mild SUI (r = 0.29).

In continent participants, perceived PFM awareness was altered when they performed PFM contractions while assuming different recumbent positions but not when they assumed different standing positions (Table 5.5). PFM awareness was perceived to be lower in the supine position (mean rank 1.53) compared to the tabletop position (mean rank 2.08) and compared to the crook-lying position (mean rank 2.39). This suggests that awareness of PFM contraction is greater among continent women in neutral lumbopelvic and hypolordotic positions than in hyperlordotic positions. Also, among continent women, perceived PFM awareness was significantly higher (z = -2.977, p = 0.003) when the hips were in lateral rotation (mean rank 2.36) compared to no rotation (mean rank 1.76).

Among participants with mild SUI, PFM awareness was perceived to be lower when contracting the PFMs, while lumbar lordosis was reduced both when lying down and when standing up (Table 5.6). Although there was a significant effect of hip rotation position on awareness among women with mild SUI (χ^2 = 6.561, p = 0.038*)* where there appeared to be a tendency for PFM awareness to be reduced in medial rotation compared

to no rotation, the post-hoc analysis did not reach significance (Table 5.6). Among women with moderate SUI symptoms, PFM contractions performed in different body positions did not result in any substantive change in awareness. A trend ($p = 0.023$) was observed though where higher awareness scores were reported when PFM contractions were performed in an upright neutral position compared to the hyperlordotic position (Table 5.7).

Table 5.2 PFM awareness in lying compared to standing

Continent Women (n=12)		*Wilcoxon*	*p-value* *(α = 0.05)*	*Effect size (r)*
Lying Position	*Standing Position*			
Supine	Hyperlordosis	$z = -2.565$	***p* = 0.010***	$r = 0.30$
Tabletop	Hypolordosis	$z = -2.877$	***p* = 0.004***	$r = 0.34$
Crook	Neutral	$z = -5.021$	***p* < 0.001***	$r = 0.59$
Mild SUI (n=10)				
Lying Position	*Standing Position*			
Supine	Hyperlordosis	$z = -1.899$	$p = 0.053$‡	$r = 0.26$
Tabletop	Hypolordosis	$z = -3.100$	***p* = 0.002***	$r = 0.42$
Crook	Neutral	$z = -2.109$	***p* = 0.035***	$r = 0.27$
Moderate SUI (n=9)				
Lying Position	*Standing Position*			
Supine	Hyperlordosis	$z = -2.369$	***p* = 0.018***	$r = 0.34$
Tabletop	Hypolordosis	$z = -3.398$	***p* = 0.001***	$r = 0.44$
Crook	Neutral	$z = -3.098$	***p* = 0.002***	$r = 0.40$

SUI (stress urinary incontinence); '*' indicates a significant position effect, '‡' indicates a trend

Table 5.3 Effect of position on PFM awareness in women without stress urinary incontinence

Continent Group (n=12)	**Effect of Position on PFM Awareness of the PFMs**				**Pairwise Differences**		
	Position			*Friedman*		*Wilcoxon*	
Hip Rotation	No Rotation	Medial rotation	Lateral rotation	*Position main effect* *(α = 0.05)*	*Pairs*	*p-value* *(α = 0.017)*	*Effect size (r)*
Median (IQR)	7.4 (2.3)	7.9 (2.3)	7.6 (1.5)	**χ^2 = 7.580, *p* = 0.023**	no rotation vs medial	*p* = 0.596	*r* = 0.06
Mean Rank	1.76	1.88	2.36		no rotation vs lateral	***p* = 0.003**	***r* = 0.35**
Lying Lumbopelvic	Crook-lying	Supine	Tabletop				
Median (IQR)	8.1 (1.0)	7.4 (2.3)	7.8 (1.8)	**χ^2 = 13.915, *p* = 0.001**	crook vs supine	***p* < 0.001**	***r* = 0.43**
Mean Rank	2.39	1.53	2.08		crook vs tabletop	*p* = 0.364	*r* = 0.11
					supine vs tabletop	***p* = 0.008**	***r* = 0.31**
Standing Lumbopelvic	Neutral	Hyper	Hypo				
Median (IQR)	6.8 (2.4)	6.5 (2.3)	6.9 (2.8)	χ^2 = 1.900, *p* = 0.387	neutral vs hyper	*p* = 0.735	*r* = 0.04
Mean Rank	2.01	1.83	2.15		neutral vs hypo	*p* = 0.868	*r* = 0.02
					hyper vs hypo	*p* = 0.164	*r* = 0.16

PFM pelvic floor muscle; PFMs pelvic floor muscles; IQR interquartile range; hyper hyperlordosis; hypo hypolordosis

Table 5.4 Effect of position on PFM awareness in women with mild SUI

Mild SUI Group (n=10)	**Effect of position on PFM awareness**				**Pairwise Differences**		
	Position			*Friedman*		*Wilcoxon*	
Hip Rotation	No Rotation	Medial rotation	Lateral rotation	*Posture main effect* *(α = 0.05)*	*Pairs*	*p-value* *(α = 0.017)*	*Effect size (r)*
Median (IQR)	6.5 (2.2)	4.9 (2.4)	6.0 (0.6)	**χ^2 = 6.561, *p* = 0.038**	no rotation vs medial	p = 0.064	r = 0.23
Mean Rank	2.28	1.61	2.11		no rotation vs lateral	p = 0.605	r = 0.20
Lying Lumbopelvic	Crook-lying	Supine	Tabletop				
Median (IQR)	5.7 (2.0)	6.5 (2.2)	5.4 (2.6)	χ^2 = 4.933, p = 0.085‡	crook vs supine	p = 0.943	r = 0.13
Mean Rank	2.28	2.04	1.69		crook vs tabletop	***p* = 0.007**	***r* = 0.37**
					supine vs tabletop	p = 0.709	r = 0.05
Standing Lumbopelvic	Neutral	Hyper	Hypo				
Median (IQR)	6.0 (1.8)	5.1 (3.9)	4.3 (4.1)	**χ^2 = 10.336, *p* = 0.006**	neutral vs hyper	p = 0.095	r = 0.23
Mean Rank	2.51	1.80	1.70		neutral vs hypo	***p* = 0.005**	***r* = 0.39**
					hyper vs hypo	p = 0.486	r = 0.10

PFM pelvic floor muscle; PFMs pelvic floor muscles; SUI stress urinary incontinence; IQR interquartile range; hyper hyperlordosis; hypo hypolordosis

Table 5.5 Effect of position on PFM awareness in women with moderate SUI

Moderate SUI Group (n=9)	**Effect of position on PFM awareness**				**Pairwise Differences**		
	Position			*Friedman*		*Wilcoxon*	
Hip Rotation	No Rotation	Medial rotation	Lateral rotation	*Posture main effect* *(α = 0.05)*	*Pairs*	*p-value* *(α = 0.017)*	*Effect size (r)*
Median (IQR)	7.1 (3.5)	6.0 (4.5)	6.2 (3.0)	$\chi^2 = 4.460$, $p = 0.108$	no rotation vs medial	$p = 0.059$	$r = 0.24$
Mean Rank	2.10	1.69	2.21		no rotation vs lateral	$p = 0.741$	$r = 0.04$
Lying Lumbopelvic	Crook-lying	Supine	Tabletop				
Median (IQR)	7.5 (2.1)	7.1 (3.5)	7.5 (1.2)	$\chi^2 = 4.259$, $p = 0.119$	crook vs supine	$p = 0.019$‡	$r = 0.30$
Mean Rank	2.18	1.70	2.12		crook vs tabletop	$p = 0.483$	$r = 0.09$
					supine vs tabletop	$p = 0.107$	$r = 0.21$
Standing Lumbopelvic	Neutral	Hyper	Hypo				
Median (IQR)	5.8 (2.6)	4.6 (3.2)	6.6 (3.5)	**$\chi^2 = 6.667$, $p = 0.036$**	neutral vs hyper	$p = 0.023$‡	$r = 0.29$
Mean Rank	2.33	1.67	2.00		neutral vs hypo	$p = 0.344$	$r = 0.12$
					hyper vs hypo	$p = 0.063$	$r = 0.24$

PFM pelvic floor muscle; PFMs pelvic floor muscles; SUI stress urinary incontinence; IQR interquartile range; hyper hyperlordosis; hypo hypolordosis

5.5 Discussion

The results of this study demonstrate differences in the perception of a PFM contraction between women with and without SUI. Continent women reported greater awareness of their PFM contractions, and when they performed these contractions while lying down, their rating of perception was correlated with performance. In contrast, when participants with SUI contracted their PFMs, their perception did not correlate with PFM EMG activation amplitude. In standing, in all groups, the correlations between PFM awareness and PFM activation amplitude were either negative or non-significant, suggesting that there may be an inaccurate perception of PFM activation when contractions are performed in standing. Therefore, self-report does not appear to provide a valid reflection of PFM EMG activation in women with SUI nor a valid reflection of performance in continent women while standing. As such, verification of correct PFM contraction through biofeedback (palpation, EMG, or ultrasound imaging (USI)) is recommended to ensure that a correct contraction is performed by all women who are prescribed PFM exercises, especially in standing. It also suggests there may be a role in specifically training PFM awareness in women who participate in a PFMT program.

Internal and external factors mediate sensory awareness of a muscle or group of muscles contracting. Afferent sensory information can be impaired by trauma (stretching, compression), pain, effusion, and fatigue (11), which subsequently can lead to a change in muscular performance (24). Altered PFM muscle performance has been identified in women with pelvic floor dysfunction (4, 7, 8, 25-27). The results from the current study suggest that those with SUI may have deficits in detecting or processing sensory information from the PFMs themselves and/or from receptors embedded in the

surrounding fascia, ligaments, and skin. These findings are consistent with suggestions in the literature that women with SUI may have difficulty perceiving PFM contractions (7, 8) and that their perceptions may not be associated with performance (16). This study represents the first attempt to quantify the perception of PFM contractions without altering direct sensory stimuli to the muscles. The findings that women with SUI have altered sensory awareness compared to continent women confirmed the hypothesis.

Pelvic floor muscle awareness had a moderate to strong association with PFM activation among the women without symptoms of SUI. The same relationship was not observed in women with SUI. Parous women, in general, and those who have vaginally delivered are more likely to have experienced trauma to their pelvic floor, including trauma to the sensory and motor nerves (28). Previous studies have suggested that women with SUI lack a local strategy for activating their PFMs and instead adopt substitution strategies (8, 27, 29) and this altered motor control may be linked to sensory deficits. Tries (30) suggested that women with SUI may develop faulty feedback loops due to reduced PFM strength or maladaptive substitution strategies when contracting the PFMs. The afferent signals from an associated muscle (e.g., gluteal, adductors) could be perceived as a PFM contraction, reinforcing its dominance in an altered motor pattern. This concept may explain why, in some positions, participants in this study who had the most severe symptoms of SUI tended to rate awareness of their PFM contraction higher than those with mild SUI. Similarly, Uechi et al. (16) reported that self-perception of a PFM contraction was only accurate in approximately 33% of participants and that those who generated less forces while contracting their PFMs (MOS $\leq$ 2) tended to overestimate the strength of their contraction. The lack of relationship between the

perception of contraction and recorded activation of the PFMs observed in this study may result from participants with moderate SUI perceiving afferent information from muscles other than their PFMs.

The impact of body position on PFM function has been evaluated in previous studies using several tools: USI to evaluate displacement of the posterior bladder base (surrogate for PFM movement) (18), EMG to evaluate activation (22), manual muscle testing (MMT) to measure strength (18), and generation of vaginal pressure (31). Frawley et al. (18) conducted a study of 20 continent women pelvic health physiotherapists to describe the influence of body position on PFM performance across four domains; digital MMT, PF displacement using transabdominal USI to measure movement of the posterior bladder base, resting vaginal pressure, and vaginal squeeze pressure. They reported that resting vaginal pressure and displacement of the posterior bladder base were higher in standing than non-standing positions and that digital MMT was lower in standing than in crook-lying or supine lying. They also reported that two participants verbally commented that the sensation of the pelvic floor contracting was different across positions. Specifically, they felt they had poorer feedback in the upright positions (sitting and standing) compared to the recumbent positions. The results presented in this chapter are both consistent with and complementary to these findings. Among women with SUI and those without, lower PFM awareness was observed in the standing positions compared to the lying down positions. The exact mechanism leading to these findings still needs to be fully understood. I hypothesized that in an upright position, the additional requirement to control posture while upright may create a situation where it is more challenging to identify and isolate the PFMs while afferent information from muscle and joint receptors

used to stay upright mask lower intensity afferent signals from the PFMs that reach the central nervous system. In upright positions, the load on the PFMs and supporting structures due to gravity alters the length and position of the PFMs (32) and could very well impact the strength of the afferent information reaching the sensorimotor cortex, minimizing the extent to which the PFMs are accurately recruited, especially in those unfamiliar with their PFMs. When recommending PFM exercises in standing, it is essential to ensure that PFM awareness and PFM performance are associated, that the execution of PFM contractions are correct, and to observe for compensatory strategies that may interfere with PFM activation.

Changes to lumbopelvic posture in standing and lying influenced PFM awareness in women with SUI. The neutral pelvic positions facilitated awareness in women with mild SUI, and awareness of the PFM contraction in the altered positions was dampened. This may have been due to competing afferent information as discussed above, where sensory information from the PFMs was masked by afferent information from the additional lumbopelvic muscles required to achieve and maintain the altered position. The VAS may have captured the participants ability to pay attention to sensory input and once out of the neutral positions there may have been additional input to pay attention too, thereby altering participants ability to notice the PFMs contracting. Continent women who demonstrated a higher level of PFM awareness overall, especially out of the neutral postures, may have been able to ignore the competing afferent information generated when sustaining the hyper- and hypolordotic postures. Further research is needed to determine the clinical relevance of this. However, these results suggest that PFM

awareness may be enhanced early in a rehabilitation program by learning to contract in a neutral position.

Many women, both with and without pelvic floor dysfunction, have difficulty learning and executing a proper PFM contraction. Motor skill acquisition requires an intact sensory system where visual, vestibular, and somatosensory inputs are well integrated. The PFMs are located deep within the pelvis, and a contraction's effect is also hidden from view. When learning to contract the PFMs, afferent information from our visual and vestibular systems is irrelevant; therefore, we likely rely heavily on somatosensory information to provide feedback to the CNS regarding this unfamiliar task. The somatosensory system involves the sense of muscle length (proprioception), movement (kinesthesia), muscle force (force sense), and effort. Mechanoreceptors are embedded in the muscles, tendons, and fascia of the pelvis, autonomic innervation of the distal vagina, as well as the skin receptors, provide most of the afferent information regarding PFM position and movement (33). Sensory awareness is a critical factor in establishing control of the PFMs and the results of this preliminary work indicate that sensory awareness deficits may be present in women with SUI. Further exploration of impairments in sensorimotor integration and their implication for conservative management of SUI is warranted.

Limitations

Presently, there is no gold standard for measuring PFM awareness. At the time this dissertation was written, PFM awareness had only been formally evaluated indirectly by having participants rate their perceived strength of contraction using a five-point scale

(16). VASs were chosen because they are simple to use, easy to understand, quick to score, and produces continuous data. It has been used and validated to measure a variety of health constructs such as pain (34), severity of depression (35), and to rate the bother associated with pelvic organ prolapse (36). The anchors used in the study may have influenced participants' interpretation of the scale, and different anchors (e.g., anchors that focused on a specific aspect of PFM recruitment like lifting or squeezing) may have generated different results. The correlation between sensory awareness and PFM activation proved to be moderate at best (in continent women), suggesting the ability of the scale to detect change in awareness relative to change in activation may have been limited. Further studies should determine the validity and reliability of different approaches to measuring sensory awareness of the PFMs.

Validity and reliability concerns have been raised when interpreting EMG amplitude characteristics recorded from the PFMs (37). This study correlated maximal PFM activation with the perception of activation across three groups of women. While PFM EMG has large variability between participants, it has excellent reproducibility within participants and within days (37). The DSE allows for the detection of PFM EMG from a localized area of the PFMs and is, therefore, less affected by crosstalk than larger commercial electrodes (38, 39). However, it is unknown how much EMG amplitudes recorded by the DSE are influenced by the movement of muscle fibers under the electrode, such as those that would have occurred based on the position changes implemented in this study. For each participant, the author who inserted and attached the DSE electrode also manually removed the electrode and was able to confirm that the electrode had remained over the bulk of the pubovisceral muscle throughout the

recording session. However, the relative position of the DSE to the same precise motor units within the PFMs may have changed when participants moved from lying to standing, which could have confounded the "between position" findings. Finally, the findings of this study are only generalizable to women who can generate a palpable contraction of their PFMs. Further research is needed to determine the impact of position on PFM awareness in those unable to contract their PFMs and to determine the relationship between diminished awareness and motor learning.

This study has shown that PFM awareness is sensitive to body position and that women with SUI demonstrate altered awareness, but it does not explain the mechanism underlying these changes. The extent to which impairments in PFM awareness impact treatment outcomes deserves further investigation, especially in the early phases of rehabilitation, where motor learning is essential to ensure that exercises are performed as prescribed. Future investigations should focus on identifying specific and robust techniques to assess PFM awareness, exploring techniques that may improve PFM awareness, and determining whether addressing deficits in PFM awareness translates into enhanced treatment outcomes.

Conclusions

The findings from this study suggest that asking a woman if she can feel her PFMs contracting may not be a valid way of assuring that she is performing a correct and maximal PFM contraction. PFM awareness was not associated with activation in women with SUI. Among continent participants, PFM awareness was positively correlated with PFM activation measured through EMG when supine but not in standing. Among those

with SUI, despite having no difference from continent participants in PFM strength measured through MOS, their PFM awareness was rated lower than that of continent participants, and their awareness generally did not correlate with PFM activity. The findings of this study reinforce the importance of verification (e.g., vaginal palpation, EMG, or ultrasound imaging) to evaluate PFM strength and motor control and the need for supervised PFM training to ensure that PFM exercises are performed correctly. The findings also indicate that different postures and positions may also be useful to improve PFM awareness.

5.6 References

1. Haylen BT, de Ridder D, Freeman RM, Swift SE, Berghmans B, Lee J, et al. An International Urogynecological Association (IUGA)/International Continence Society (ICS) joint report on the terminology for female pelvic floor dysfunction. Neurourol Urodyn. 2010;29(1):4-20.

2. Bo K, Stien R, Kulseng-Hanssen S, Kristofferson M. Clinical and urodynamic assessment of nulliparous young women with and without stress incontinence symptoms: a case-control study. Obstet Gynecol. 1994;84(6):1028-32.

3. Gunnarsson M, Teleman P, Mattiasson A, Lidfeldt J, Nerbrand C, Samsioe G. Effects of pelvic floor exercises in middle aged women with a history of naive urinary incontinence: a population based study. Eur Urol. 2002;41(5):556-61.

4. Morin M, Bourbonnais D, Gravel D, Dumoulin C, Lemieux MC. Pelvic floor muscle function in continent and stress urinary incontinent women using dynamometric measurements. Neurourol Urodyn. 2004;23(7):668-74.

5. Dumoulin C, Hay-Smith J, Habee-Seguin GM, Mercier J. Pelvic floor muscle training versus no treatment, or inactive control treatments, for urinary incontinence in women: a short version Cochrane systematic review with meta-analysis. Neurourol Urodyn. 2015;34(4):300-8.

6. Smith MD, Coppieters MW, Hodges PW. Postural response of the pelvic floor and abdominal muscles in women with and without incontinence. Neurourol Urodyn. 2007;26(3):377-85.

7. Devreese A, Staes F, De Weerdt W, Feys H, Van Assche A, Penninckx F, et al. Clinical evaluation of pelvic floor muscle function in continent and incontinent women. Neurourol Urodyn. 2004;23(3):190-7.

8. Thompson JA, O'Sullivan PB, Briffa NK, Neumann P. Altered muscle activation patterns in symptomatic women during pelvic floor muscle contraction and Valsalva manouevre. Neurourol Urodyn. 2006;25(3):268-76.

9. Smith MD, Coppieters MW, Hodges PW. Postural activity of the pelvic floor muscles is delayed during rapid arm movements in women with stress urinary incontinence. Int Urogynecol J Pelvic Floor Dysfunct. 2007;18(8):901-11.

10. Smith MD, Coppieters MW, Hodges PW. Is balance different in women with and without stress urinary incontinence? Neurourol Urodyn. 2008;27(1):71-8.

11. Roijezon U, Clark NC, Treleaven J. Proprioception in musculoskeletal rehabilitation. Part 1: Basic science and principles of assessment and clinical interventions. Man Ther. 2015;20(3):368-77.

12. Mahoney C, Smith A, Marshall A, Reid F. Pelvic floor dysfunction and sensory impairment: Current evidence. Neurourol Urodyn. 2017;36(3):550-6.

13. Kenton K, Mueller E, Brubaker L. Continent women have better urethral neuromuscular function than those with stress incontinence. Int Urogynecol J. 2011;22(12):1479-84.

14. Gill BC, Moore C, Damaser MS. Postpartum stress urinary incontinence: lessons from animal models. Expert Rev Obstet Gynecol. 2010;5(5):567-80.

15. Kharaji G, Nikjooy A, Amiri A, Sanjari MA. Proprioception in stress urinary incontinence: A narrative review. Med J Islam Repub Iran. 2019;33:60.

16. Uechi N, Fernandes A, Bo K, de Freitas LM, de la Ossa AMP, Bueno SM, et al. Do women have an accurate perception of their pelvic floor muscle contraction? A cross-sectional study. Neurourol Urodyn. 2020;39(1):361-6.

17. Bo K, Sherburn M. Evaluation of female pelvic-floor muscle function and strength. Phys Ther. 2005;85(3):269-82.

18. Frawley HC, Galea MP, Phillips BA, Sherburn M, Bo K. Effect of test position on pelvic floor muscle assessment. Int Urogynecol J Pelvic Floor Dysfunct. 2006;17(4):365-71.

19. Kelly M, Tan BK, Thompson J, Carroll S, Follington M, Arndt A, et al. Healthy adults can more easily elevate the pelvic floor in standing than in crook-lying: an experimental study. Aust J Physiother. 2007;53(3):187-91.

20. Capson AC, Nashed J, McLean L. The role of lumbopelvic posture in pelvic floor muscle activation in continent women. J Electromyogr Kinesiol. 2011;21(1):166-77.

21. Deindl FM, Vodusek DB, Hesse U, Schussler B. Activity patterns of pubococcygeal muscles in nulliparous continent women. Br J Urol. 1993;72(1):46-51.

22. Madill SJ, McLean L. Quantification of abdominal and pelvic floor muscle synergies in response to voluntary pelvic floor muscle contractions. J Electromyogr Kinesiol. 2008;18(6):955-64.

23. Fritz CO, Morris PE, Richler JJ. Effect size estimates: current use, calculations, and interpretation. J Exp Psychol Gen. 2012;141(1):2-18.

24. Konishi Y, Fukubayashi T, Takeshita D. Possible mechanism of quadriceps femoris weakness in patients with ruptured anterior cruciate ligament. Med Sci Sports Exerc. 2002;34(9):1414-8.

25. Deindl FM, Vodusek DB, Hesse U, Schussler B. Pelvic floor activity patterns: comparison of nulliparous continent and parous urinary stress incontinent women. A kinesiological EMG study. Br J Urol. 1994;73(4):413-7.

26. Gunnarsson M, Mattiasson A. Female stress, urge, and mixed urinary incontinence are associated with a chronic and progressive pelvic floor/vaginal neuromuscular disorder: An investigation of 317 healthy and incontinent women using vaginal surface electromyography. Neurourol Urodyn. 1999;18(6):613-21.

27. Madill SJ, Harvey MA, McLean L. Women with SUI demonstrate motor control differences during voluntary pelvic floor muscle contractions. Int Urogynecol J Pelvic Floor Dysfunct. 2009;20(4):447-59.

28. Hallock JL, Handa VL. The Epidemiology of Pelvic Floor Disorders and Childbirth: An Update. Obstet Gynecol Clin North Am. 2016;43(1):1-13.

29. O'Sullivan P, Twomey L, Allison G, Sinclair J, Miller K. Altered patterns of abdominal muscle activation in patients with chronic low back pain. Aust J Physiother. 1997;43(2):91-8.

30. Tries J. Kegel exercises enhanced by biofeedback. J Enterostomal Ther. 1990;17(2):67-76.

31. Bo K, Finckenhagen HB. Is there any difference in measurement of pelvic floor muscle strength in supine and standing position? Acta Obstet Gynecol Scand. 2003;82(12):1120-4.

32. Dietz HP, Clarke B. The influence of posture on perineal ultrasound imaging parameters. Int Urogynecol J Pelvic Floor Dysfunct. 2001;12(2):104-6.

33. O'Connell HE, Eizenberg N, Rahman M, Cleeve J. The anatomy of the distal vagina: towards unity. J Sex Med. 2008;5(8):1883-91.

34. Reed MD, Van Nostran W. Assessing pain intensity with the visual analog scale: a plea for uniformity. J Clin Pharmacol. 2014;54(3):241-4.

35. Huang Z, Kohler IV, Kampfen F. A Single-Item Visual Analogue Scale (VAS) Measure for Assessing Depression Among College Students. Community Ment Health J. 2020;56(2):355-67.

36. Yu H, Shek KL, Gillor M, Descallar J, Dietz HP. Is the Visual Analogue Scale inferior to the Pelvic Organ Prolapse Distress Inventory for assessing symptom bother of pelvic organ prolapse? Aust N Z J Obstet Gynaecol. 2021;61(6):918-21.

37. Auchincloss CC, McLean L. The reliability of surface EMG recorded from the pelvic floor muscles. J Neurosci Methods. 2009;182(1):85-96.

38. Keshwani N, McLean L. Development of a differential suction electrode for improved intravaginal recordings of pelvic floor muscle activity: reliability and motion artifact assessment. Neurourol Urodyn. 2012;31(8):1272-8.

39. Keshwani N, McLean L. A differential suction electrode for recording electromyographic activity from the pelvic floor muscles: crosstalk evaluation. J Electromyogr Kinesiol. 2013;23(2):311-8.

Chapter 6

General Discussion

6.1 Introduction and Purpose of Dissertation

Pelvic floor muscle training (PFMT) has been shown to improve and, in many cases, alleviate symptoms of stress urinary incontinence (SUI). It is estimated that PFMT can have a five-fold increase in cure rate compared to no treatment (1). The ability to contract the pelvic floor muscles (PFMs), the appropriate dose of exercise, and adherence to the exercise program contribute to a successful PFMT program (2). Yet one-third of women cannot perform a proper PFM contraction when provided with verbal instruction (3), and they require specific instructions and facilitation techniques when learning to contract their PFMs. Several studies have suggested that PFM sensory awareness may be compromised in women with SUI (4-7), and preliminary work exploring PFM proprioceptive sense is emerging (7, 8). A deficit in sensory feedback when learning to contract the PFMs properly may compromise the motor learning process and reduce the effectiveness of PFMT. Sensory awareness of the PFMs during maximal voluntary contractions (MVCs) has yet to be quantified. The suction technology of the differential suction electrode (DSE) and its small size allowed us to capture the activation of the levator ani with low probability of motion artifact and crosstalk contamination (9, 10) while concurrently evaluating PFM awareness.

Sensory feedback is embedded in the motor learning process (11). Thus, altered sensory awareness of the PFMs in women with SUI may interfere with motor learning,

which could impact PFMT outcomes (2). To the author's knowledge, this is the first study in which awareness of PFM contraction has been studied systematically, and the first study in which the impact of hip position on both PFM activation and on the accuracy of perception of PFM activation have been evaluated. Through the research presented in this thesis, the author aimed to measure sensory awareness of the PFMs, to compare PFM activation and sensory awareness characteristics between women with and without SUI, to explore the relationship between PFM electromyographic activation and PFM awareness, and finally, to describe the effect of body position, hip position, and lumbopelvic posture on PFM activation and sensory awareness in women with and without SUI.

6.2 Summary of Individual Studies

The first study in the thesis, entitled "Lumbopelvic posture influences the electromyographic activity of the pelvic floor muscles in women with and without stress urinary incontinence," (Chapter 3) compared PFM activation between women without SUI and those with mild and moderate SUI while they assumed different lumbopelvic postures (neutral, hyperlordosis, hypolordosis) in two different body positions (lying and standing). Electromyography (EMG) data were recorded from the PFMs at rest (tonic activation) and during maximal effort voluntary contractions using the DSE (9, 10) suctioned to the vaginal wall adjacent to the deep PFMs. We described the effects of body position and lumbopelvic posture on tonic and maximal PFM activation in each cohort and compared activation amplitudes among the three groups. Maximal PFM activation was lowest in women with moderate SUI ($p \leq 0.011$, effect size $r = 0.35$ -

0.85). They were the only cohort to generate lower maximal activation amplitudes standing than lying (z = -3.391, p = 0.001), indicating that a deficit in neuromuscular activation may be present in those with moderate but not mild SUI symptoms. This finding may suggest a different underlying pathophysiology of SUI based on severity, or that severity of symptoms causes women to employ different compensation strategies to achieve continence. When postural demands and gravitational load were minimized by lying, tonic PFM activation was lower than it was in standing ($p < 0.001$). We concluded that both tonic and maximal PFM activation were affected by body position and lumbopelvic posture, and that stratifying women based on symptom severity for research purposes should be considered in study designs. While changing body position and lumbopelvic posture may be an effective strategy to improve PFM activation, the effects are variable and thus strategies must be individualized.

In the second study, entitled "The effect of hip position on pelvic floor muscle activation in women with and without stress urinary incontinence" (Chapter 4), we described the effect of hip rotation and hip flexion positions on PFM activation at rest (tonic activation) and during voluntary PFM contractions (maximal activation) in women with and without SUI. We compared tonic and maximal PFM activation amplitudes across the different hip positions and among the groups. The hip muscles are anatomically and functionally linked with the PFMs, where assuming different hip flexion and hip rotation positions were thought to impact the length and tension of the PFMs. In agreement with the findings in Chapter 3, women with moderate SUI generated the lowest maximal PFM activation amplitudes in all test positions ($p \leq 0.011$, effect size r = 0.32 - 0.46). Tonic PFM activation was lower with hip flexion (tabletop position) than

hip extension (supine), but this effect was only significant in women without SUI (z = -2.262, p = 0.024) and those with moderate SUI (z = -3.157, p = 0.002). Even though hip rotation influenced PFM activation, the effect was inconsistent among cohorts and differed when the hips were rotated in the flexed and extended positions. The influence of hip flexion and hip rotation on PFM activation may be impacted by PFM mass, collagen content of the dense network of connective tissue in the pelvic floor, and motor control strategies used to maintain the test position. The findings of this study suggest that attention should be given to hip position when prescribing PFM exercises, and that the use of different hip positions may facilitate or inhibit PFM activation. Hip flexion with the legs fully supported appears to lower tonic PFM activation, and this position may be helpful to use during treatment when the goal is to reduce PFM tone, such as during a speculum examination.

In the final study of this dissertation, entitled "Pelvic floor muscle awareness is lower among women with stress urinary incontinence compared to those without stress urinary incontinence," (Chapter 5) we explored sensory awareness of the PFMs contracting. We used a visual analogue scale (VAS) to describe and compare women's awareness of the PFMs contracting among three cohorts of women: those without SUI, those with mild SUI, and those with moderate SUI while they performed PFM voluntary contractions in different positions. We described the relationship between maximal PFM activation and PFM awareness, and we explored the influence of body position, hip position, and lumbopelvic posture on sensory awareness. The results of this study suggest that reported PFM awareness often does not reflect actual PFM activation, especially among those with SUI. Body position and posture influenced PFM awareness, where the

effect depended on continence status, similar to what was reported in Chapter 3 and Chapter 4.

In conclusion, the findings of Chapter 5 suggest that PFM awareness is altered in women with SUI, where the effect varies by severity of symptoms. It is beyond the scope of this dissertation to explain with certainty why such impairment in PFM awareness is present. Understanding the mechanisms behind the impairment and the implication for rehabilitation deserves more attention.

6.3 Integrated Discussion and Disciplinary Implications

Four key points can be taken from this thesis: 1) PFM awareness is altered in women with SUI, 2) perceived PFM awareness is not always associated with PFM performance, 3) position and posture influence both PFM activation and PFM awareness, and 4) symptom severity should be considered when comparing women with and without SUI. This is the first study in which the relationship between PFM activation and sensory awareness is explored, and one of few studies in which PFM awareness was quantified without additional sensory feedback stemming from palpation or other PFM measurement tools that may influence awareness. The results highlight the importance of directing more attention towards the role of sensory awareness and proprioceptive sense to fully understand PFM function and dysfunction as it relates to SUI and PFMT.

The results of Chapter 5 demonstrate that PFM awareness can be described using the VAS in women with and without SUI. The VAS was easy to use, measurable, and sensitive to changes in body position and posture. Significant differences in perceived awareness among three cohorts using the VAS were also detected. Future research should aim to validate the use of VAS to measure PFM awareness using appropriate anchors. We

have long suspected that the sensory awareness of the PFMs may be compromised in women with SUI (6, 7, 12-14); this is the first study to quantify perceived sensory awareness using VAS in women with and without SUI and the first to examine the effect of body position, hip position, and lumbopelvic posture on sensory awareness.

While delivering pelvic re-education physiotherapy, it is essential to consider the qualitative aspect of PFM awareness and to compare the perceived sensory experience with actual performance characteristics to determine the accuracy of the afferent input feeding motor output. Depending on the clinical setting or research questions, PFM performance may be measured using palpation, dynamometry, EMG, ultrasound imaging, or manometry. Confirming that what one feels as one contracts is an accurate reflection of what the PFMs are doing may be essential early in rehabilitation and when new exercise positions are introduced as the PFMT program progresses. Refining the acuity of the proprioceptive system by aiming to align sensory awareness and PFM performance may enhance the effectiveness of PFMT to eliminate SUI symptoms. Even in women without SUI there was a negative relationship between PFM awareness and activation in standing. Future research is warranted to determine if sensory awareness training improves PFM performance and ultimately improves treatment outcomes.

In this small sample, PFM activation amplitude, PFM awareness, and the response to altered postures and positions differed among cohorts; however, some of the findings would have been missed without stratifying the SUI cohort by severity. Likewise, Smith et al. (15) and Madill et al. (16) also presented their results where symptom severity was considered, demonstrating motor control differences among the groups that may have otherwise not been discovered. Moving forward, researchers should consider the severity

of incontinence symptoms when examining aspects of PFM performance and the response to intervention. Reporting findings based on severity of symptoms may reveal significant differences between those with mild and more severe symptoms of SUI that will help advance treatment options and improve treatment outcomes.

Body position, hip position, and lumbopelvic posture influenced PFM activation and awareness in women with and without SUI. Position and posture should not be overlooked when assessing the PFMs and when prescribing PFM exercises. A few themes emerged when results were integrated among the chapters that deserve further attention. When the body is stable, and in neutral positions, where postural demands on the pelvic floor are minimal, awareness and maximal activation may be optimal early in a rehabilitation program. Competing afferents from additional loading on the pelvic floor, increased postural demand, or challenges to the system's stability may overload the sensory system and impact both activation and awareness. Body position and posture may be utilized clinically to facilitate or inhibit PFM function (activation and sensory awareness); however, the effect may be unique to the individual and needs to be confirmed objectively.

6.4 Limitations

The results of this work contribute to our understanding of PFM motor control in women with SUI and have presented a novel method for quantifying PFM sensory awareness; however, some limitations need to be addressed. The sample size in each group was small, and the data were not normally distributed, necessitating nonparametric statistical analysis. The studies were preliminary investigations to determine if body

position, hip position, and lumbopelvic postures would produce measurable changes in PFM EMG and if the VAS could measure perceived awareness of the PFMs contracting. Even with the small sample and the conservative analysis approach, we saw a significant effect of position on PFM awareness and PFM activation. Small sample sizes are not unfamiliar to the PFM motor control literature, where several important discoveries that have shaped our understanding of PFM motor control, in women with SUI and in women without SUI, were identified using cohorts of 8 to 17 participants (5, 6, 12, 15, 17, 18). The small numbers limit the generalizability of the findings. Women who could not contract their PFMs were excluded from participating in the study, even though we recognize that this cohort may benefit the most from sensory awareness training. This work has contributed to the establishment of a foundation for more extensive studies to explore PFM awareness in women with and without SUI, specifically, those women who have difficulty contracting their PFMs in greater depth.

A VAS is simple and quick to administer, and it has been used in healthcare research for decades as a patient-reported outcome measure, frequently used to measure pain intensity (19). Despite the wide use of VAS in health care research (19, 20) and specifically in urogynecology (21, 22), the tool's validity, reliability, and responsiveness to measure PFM awareness has yet to be established. Even though perceived PFM awareness scores were determined to be statistically different among the groups and between positions, the clinical relevance of the differences has yet to be discovered as we have no reference to population norms outside of this convenience sample of women without SUI who participated in this study.

The EMG data recorded in this work were not normalized. Normalization is the process of converting the raw EMG signal to a scale relative to a known value, such as peak activation amplitude during a maximal effort contraction, to eliminate some of the variable intrinsic and extrinsic muscle factors known to impact signal amplitude (23, 24). Normalization is typically recommended when using surface EMG data to compare between days, groups, or muscles (24). However, evidence suggests that women with pelvic floor dysfunction struggle to contract their PFMs (14, 25-27), which may impact the validity of using a maximal contraction as a reference contraction. A recent consensus report states that the raw EMG signal can be analyzed with caution when participants cannot perform appropriate reference contractions (pain, neuromuscular limitations, motor control dysfunction) or when the task of interest is a maximal effort contraction (28). Using either a maximal effort contraction or standardized submaximal task to perform the normalization procedure may have biased the data more than not normalizing in the first place.

The PFMs work in synergy with other muscles of the lumbopelvic area (6, 18), and there is evidence that recruitment patterns differ between those with and without SUI (6, 16). Even though we understand how important evaluating the global system is in terms of motor control, we pre-emptively decided to only record EMG locally from the PFMs. The main objectives of this study were to quantify PFM sensory awareness and to understand whether and how PFM activation and PFM awareness are altered when women assume different positions. Analyzing digitized positional information and abdominal muscle activation data may have added to our understanding of PFM activation and awareness as well as the impact of positional changes. However, when

surface electrodes are used where body mass index (BMI) is high, the EMG is not necessarily valid; elevated BMI is a known risk factor for SUI (29).

Continence status and severity of continence symptoms were determined for the study using validated self-report questionnaires (30, 31). We did not confirm the presence or severity of incontinence using urodynamic studies (UDS) or a standardized pad test (32). The presence or absence of stress-induced leakage was first determined using screening questions during the eligibility interview. Continence status was then confirmed using answers from the questionnaires. Participants deemed to have SUI were further subdivided by severity using the ICIQ-SF questionnaire, which demonstrated a high correlation (Spearman's rho = 0.62 to 0.71, $p < 0.001$) with the Incontinence Severity Index (33) and has good construct validity and test re-test reliability (Crohnbach's alpha = 0.95) (31). The ICIQ-SF is a robust measure that is simple to complete and is often used in incontinence research.

A digital palpation examination was performed on all participants, where PFM muscle strength and tone were graded according to clinically accepted standards. Women who could not recruit their PFMs, even after brief instruction and tactile feedback techniques were used, were deemed ineligible to participate. Excluding women who cannot perform a PFM contraction has been questioned in the literature as reducing the generalizability of the results. It has been suggested that approximately 30% of women, those with symptoms and without, cannot contract their PFMs (25), and often, these women are excluded from participating in research studies aimed at exploring the neuromuscular control of the PFMs (6, 13, 16, 34). Only one volunteer was excluded from this research when it was determined that she could not contract their PFMs,

however, this exclusion does limit the generalizability of the findings. Future steps include exploring sensory awareness deficits that may be present in those who struggle to contract their PFMs and determining if awareness training strategies can facilitate contractility and PFM function.

The author, who completed the data collection procedures was not blind to participants cohort during the data collection process; however, during the data extraction and analysis process, I did not know group allocations of the data sets. Data were stored by identification numbers where their continence status and severity were unmarked.

6.5 Conclusion

The results of this dissertation contribute to our understanding of sensorimotor function of the PFMs in women with SUI, which is in its infancy (7). Perceived PFM awareness was rated by participants using a common and accepted subjective rating scale (VAS). Neuromuscular activation of the PFMs was examined using advanced suction technology (DSE). In summary, the results suggest that sensorimotor function of the PFMs may be compromised in women with SUI, PFM awareness was not always associated with activation, even in women without SUI when standing, and posture and position impact both neuromuscular activation and PFM awareness. Sensorimotor function also appears to be dependent on severity of symptoms and should be routinely addressed when conducting research and delivering PFMT intervention.

6.6 References

1. Dumoulin C, Cacciari LP, Hay-Smith EJC. Pelvic floor muscle training versus no treatment, or inactive control treatments, for urinary incontinence in women. Cochrane Database Syst Rev. 2018;10:CD005654.

2. Hay-Smith J, Dean S, Burgio K, McClurg D, Frawley H, Dumoulin C. Pelvic-floor-muscle-training adherence "modifiers": A review of primary qualitative studies-2011 ICS State-of-the-Science Seminar research paper III of IV. Neurourol Urodyn. 2015;34(7):622-31.

3. Zubieta M, Carr RL, Drake MJ, Bø K. Influence of voluntary pelvic floor muscle contraction and pelvic floor muscle training on urethral closure pressures: a systematic literature review. International Urogynecology Journal. 2016;27(5):687-96.

4. Uechi N, Fernandes A, Bo K, de Freitas LM, de la Ossa AMP, Bueno SM, et al. Do women have an accurate perception of their pelvic floor muscle contraction? A cross-sectional study. Neurourol Urodyn. 2020;39(1):361-6.

5. Sapsford RR, Richardson CA, Stanton WR. Sitting posture affects pelvic floor muscle activity in parous women: an observational study. Aust J Physiother. 2006;52(3):219-22.

6. Thompson JA, O'Sullivan PB, Briffa NK, Neumann P. Altered muscle activation patterns in symptomatic women during pelvic floor muscle contraction and Valsalva manouevre. Neurourol Urodyn. 2006;25(3):268-76.

7. Kharaji G, Nikjooy A, Amiri A, Sanjari MA. Proprioception in stress urinary incontinence: A narrative review. Med J Islam Repub Iran. 2019;33:60.

8. Brooks K, McLean L, editors. A novel dynamometry-based method to assess female levator ani muscle proprioception. Abstract 281. International Continence Society 2023 Sept 27-29, 2023; Toronto, Canada. Neurourology and Urodynamics.

9. Keshwani N, McLean L. Development of a differential suction electrode for improved intravaginal recordings of pelvic floor muscle activity: reliability and motion artifact assessment. Neurourol Urodyn. 2012;31(8):1272-8.

10. Keshwani N, McLean L. A differential suction electrode for recording electromyographic activity from the pelvic floor muscles: crosstalk evaluation. Journal of electromyography and kinesiology : official journal of the International Society of Electrophysiological Kinesiology. 2013;23(2):311-8.

11. Ostry DJ, Gribble PL. Sensory Plasticity in Human Motor Learning. Trends Neurosci. 2016;39(2):114-23.

12. Smith MD, Coppieters MW, Hodges PW. Postural activity of the pelvic floor muscles is delayed during rapid arm movements in women with stress urinary incontinence. Int Urogynecol J Pelvic Floor Dysfunct. 2007;18(8):901-11.

13. Smith MD, Coppieters MW, Hodges PW. Is balance different in women with and without stress urinary incontinence? Neurourol Urodyn. 2008;27(1):71-8.

14. Devreese A, Staes F, De Weerdt W, Feys H, Van Assche A, Penninckx F, et al. Clinical evaluation of pelvic floor muscle function in continent and incontinent women. Neurourol Urodyn. 2004;23(3):190-7.

15. Smith MD, Coppieters MW, Hodges PW. Postural response of the pelvic floor and abdominal muscles in women with and without incontinence. Neurourol Urodyn. 2007;26(3):377-85.

16. Madill SJ, Harvey MA, McLean L. Women with SUI demonstrate motor control differences during voluntary pelvic floor muscle contractions. Int Urogynecol J Pelvic Floor Dysfunct. 2009;20(4):447-59.

17. Sapsford RR, Richardson CA, Maher CF, Hodges PW. Pelvic floor muscle activity in different sitting postures in continent and incontinent women. Arch Phys Med Rehabil. 2008;89(9):1741-7.

18. Madill SJ, McLean L. Quantification of abdominal and pelvic floor muscle synergies in response to voluntary pelvic floor muscle contractions. J Electromyogr Kinesiol. 2008;18(6):955-64.

19. Chiarotto A, Maxwell LJ, Ostelo RW, Boers M, Tugwell P, Terwee CB. Measurement Properties of Visual Analogue Scale, Numeric Rating Scale, and Pain Severity Subscale of the Brief Pain Inventory in Patients With Low Back Pain: A Systematic Review. J Pain. 2019;20(3):245-63.

20. Ohnhaus EE, Adler R. Methodological problems in the measurement of pain: a comparison between the verbal rating scale and the visual analogue scale. Pain. 1975;1(4):379-84.

21. Ulrich D, Guzman Rojas R, Dietz HP, Mann K, Trutnovsky G. Use of a visual analog scale for evaluation of bother from pelvic organ prolapse. Ultrasound Obstet Gynecol. 2014;43(6):693-7.

22. Lukacz ES, Santiago-Lastra Y, Albo ME, Brubaker L. Urinary Incontinence in Women: A Review. JAMA. 2017;318(16):1592-604.

23. De Luca CJ. The use of surface electromyography in biomechanics. Journal of Applied Biomechanics. 1997;13:135-63.

24. Burden A. How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research. J Electromyogr Kinesiol. 2010;20(6):1023-35.

25. Bo K, Sherburn M. Evaluation of female pelvic-floor muscle function and strength. Phys Ther. 2005;85(3):269-82.

26. Pereira LC, Botelho S, Marques J, Adami DB, Alves FK, Palma P, et al. Electromyographic pelvic floor activity: Is there impact during the female life cycle? Neurourol Urodyn. 2016;35(2):230-4.

27. Kegel AH. Stress incontinence and genital relaxation; a nonsurgical method of increasing the tone of sphincters and their supporting structures. Ciba Clin Symp. 1952;4(2):35-51.

28. Besomi M, Hodges PW, Clancy EA, Van Dieen J, Hug F, Lowery M, et al. Consensus for experimental design in electromyography (CEDE) project: Amplitude normalization matrix. J Electromyogr Kinesiol. 2020;53:102438.

29. Hunskaar S, Lose G, Sykes D, Voss S. The prevalence of urinary incontinence in women in four European countries. BJU Int. 2004;93(3):324-30.

30. Uebersax JS, Wyman JF, Shumaker SA, McClish DK, Fantl JA. Short forms to assess life quality and symptom distress for urinary incontinence in women: the Incontinence Impact Questionnaire and the Urogenital Distress Inventory. Continence Program for Women Research Group. Neurourol Urodyn. 1995;14(2):131-9.

31. Avery K, Donovan J, Peters TJ, Shaw C, Gotoh M, Abrams P. ICIQ: a brief and robust measure for evaluating the symptoms and impact of urinary incontinence. Neurourol Urodyn. 2004;23(4):322-30.

32. Dillon BE, Zimmern PE. When are urodynamics indicated in patients with stress urinary incontinence? Curr Urol Rep. 2012;13(5):379-84.

33. Klovning A, Avery K, Sandvik H, Hunskaar S. Comparison of two questionnaires for assessing the severity of urinary incontinence: The ICIQ-UI SF versus the incontinence severity index. Neurourol Urodyn. 2009;28(5):411-5.

34. Capson AC, Nashed J, McLean L. The role of lumbopelvic posture in pelvic floor muscle activation in continent women. J Electromyogr Kinesiol. 2011;21(1):166-77.

Appendix A

Ethics REH-439-08

QUEEN'S UNIVERSITY HEALTH SCIENCES AND AFFILIATED TEACHING HOSPITALS RESEARCH ETHICS BOARD ANNUAL RENEWAL

Queen's University, in accordance with the "Tri-Council Policy Statement 2, 2010" prepared by the Interagency Advisory Panel on Research Ethics for the Canadian Institutes of Health Research, Natural Sciences and Engineering Research Council of Canada and Social Sciences and Humanities Research Council of Canada requires that research projects involving human participants be reviewed annually to determine their acceptability on ethical grounds.

A Research Ethics Board composed of:

Dr. A.F. Clark, Emeritus Professor, Department of Biomedical and Molecular Sciences, Queen's University (Chair)
Dr. H. Abdollah, Professor, Department of Medicine, Queen's University
Dr. C. Cline, Assistant Professor, Department of Medicine, Director, Office of Bioethics, Queen's University, Clinical Ethicist, Kingston General Hospital
Dr. R. Brison, Professor, Department of Emergency Medicine, Queen's University
Dr. M. Evans, Community Member
Ms. J. Hudacin, Community Member
Mr. D. McNaughton, Community Member
Ms. P. Newman, Pharmacist, Clinical Care Specialist and Clinical Lead, Quality and Safety, Pharmacy Services, Kingston General Hospital
Ms. S. Rohland, Privacy Officer, ICES-Queen's Health Services Research Facility, Research Associate, Division of Cancer Care and Epidemiology, Queen's Cancer Research Institute
Dr. A. Singh, Professor, Department of Psychiatry, Queen's University
Dr. J. Walia, Assistant Professor and Clinical Geneticist, Department of Paediatrics, Queen's University and Kingston General Hospital
Ms. K. Weisbaum, LL.B. and Adjunct Instructor, Department of Family Medicine (Bioethics)

has reviewed the request for renewal of Research Ethics Board approval for the project **"The Effect of Lumbopelvic Posture on Abdominal and Pelvic Floor Muscle Activity in Women"** as proposed by **Dr. L. McLean** of the School of Rehabilitation Therapy, at Queen's University. The approval is renewed for one year, effective **April 24, 2014**. If there are any further amendments or changes to the protocol affecting the participants in this study, it is the responsibility of the principal investigator to notify the Research Ethics Board. Any unexpected serious adverse event occurring locally must be reported within 2 working days or earlier if required by the study sponsor. All other adverse events must be reported within 15 days after becoming aware of the information.

Date: April 24, 2014 Chair, Health Sciences Research Ethics Board
Renewal 1[ ] Renewal 2 [ ] Extension [x] **Code# REH-439-08 Romeo file# 6004377**

Appendix B

Recruitment Advertisement

Does someone you know leak urine when they cough, laugh or sneeze?

We are looking for women who DO <u>and</u> those who DO NOT leak urine
with activities such as coughing / laughing / sneezing / lifting / walking / running
to participate in a study investigating the impact of posture and hip position on pelvic floor muscle activation.

<u>To be eligible to participate you:</u>

- Must be between the ages of 18 and 70
- Must be free from low back and pelvic pain
- Must not be pregnant or not have given birth in the past 12-months

<u>What is involved?</u>

1. Initial telephone interview to determine eligibility (10 minutes)

2. A visit to the Pelvic Floor Laboratory where your pelvic floor muscle activation will be recorded while you contract your muscles in different postures and hip positions (2 hours).

<u>Interested?</u>

For more information please contact the Pelvic Floor Research Lab at
Phone: 613 533 6000 ext. 79009 or
E-mail: pelvicfloorstudy@gmail.com (Subject: posture study)

Appendix C

Incontinence Questionnaires

International Consultation on Incontinence Questionnaire Urinary Incontinence Short Form (ICIQ-UI SF)

Urinary Distress Inventory-6 (UDI-6) and Incontinence Impact Questionnaire-7 (IIQ-7)

Initial number
Today's date

ICIQ-UI Short Form

CONFIDENTIAL

DAY MONTH YEAR

Many people leak urine some of the time. We are trying to find out how many people leak urine, 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.

1 Please write in your date of birth:

DAY MONTH YEAR

2 Are you *(tick one)*: Female ☐ Male ☐

3 How often do you leak urine? *(Tick one box)*

never ☐	0
about once a week or less often ☐	1
two or three times a week ☐	2
about once a day ☐	3
several times a day ☐	4
all the time ☐	5

4 We would like to know how much urine <u>you think</u> leaks.
How much urine do you <u>usually</u> leak (whether you wear protection or not)?
(Tick one box)

none ☐	0
a small amount ☐	2
a moderate amount ☐	4
a large amount ☐	6

5 Overall, how much does leaking urine interfere with your everyday life?
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

ICIQ score: sum scores 3+4+5 ☐☐

6 When does urine leak? *(Please tick all that apply to you)*

never – urine does not leak ☐
leaks before you can get to the toilet ☐
leaks when you cough or sneeze ☐
leaks when you are asleep ☐
leaks when you are physically active/exercising ☐
leaks when you have finished urinating and are dressed ☐
leaks for no obvious reason ☐
leaks all the time ☐

Thank you very much for answering these questions.

UDI-6/IIQ-7 Evaluation of Female Incontinence

Last Name	First Name	Date of Birth	Date

Do you experience, and, if so, how much are you bothered by:					
		Not at all	Slightly	Moderately	Greatly
1.	Frequent urination	**0**	**1**	**2**	**3**
2	Urine leakage related to feeling of urgency?	**0**	**1**	**2**	**3**
3	Urine leakage related to physical activity, coughing or sneezing?	**0**	**1**	**2**	**3**
4	Small amounts of urine leakage (drops)?	**0**	**1**	**2**	**3**
5	Difficulty emptying your bladder	**0**	**1**	**2**	**3**
6	Pain or discomfort in the lower abdominal area?	**0**	**1**	**2**	**3**
	Nighttime urination?	**0**	**1**	**2**	**3**
	A strong feeling of urgency to empty your bladder?	**0**	**1**	**2**	**3**

Urogenital Distress Inventory (UDI-6+2) ***Total score..... /18***

Has urine leakage and /or prolapse affected your:					
		Not at all	Slightly	Moderately	Greatly
1	Ability to do household chores (cooking, housecleaning, laundry)?	**0**	**1**	**2**	**3**
2	Physical recreation such as walking, swimming, or other exercise?	**0**	**1**	**2**	**3**
3	Entertaining activities (movies, concerts, etc)?	**0**	**1**	**2**	**3**
4	Ability to travel by car or bus more than 30 minutes from home?	**0**	**1**	**2**	**3**
5	Participation in social activities outside your home?	**0**	**1**	**2**	**3**
6	Emotional health (nervousness, depression, etc.)?	**0**	**1**	**2**	**3**
7	Feeling frustrated?	**0**	**1**	**2**	**3**
	Ability to have sexual relations?	**0**	**1**	**2**	**3**

Incontinence Impact Questionnaire (IIQ-7+1) ***Total score..... /21***

Uebersax JS, Wyman JF, Shumaker SA, et al.: Short forms to assess life quality and symptom distress for urinary incontinence in women: the incontinence impact questionnaire and the urogenital distress inventory. Neurourol Urodyn 1995, 14: 131-139.