Pelvic Floor Muscle Function During Gait

by
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Declaration

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Abstract

Introduction: The pelvic floor muscles (PFMs) contribute to visceral control, including bladder bowel and sexual function. There is strong evidence in support of PFM retraining as first line conservative management of pelvic floor disorders. Investigations into PFM activity and function have often been conducted in lying, for subject comfort and investigator convenience. Recent technological advances have allowed for investigations into PFM function in weightbearing and during physical activity. **Aims:** To establish current practise in measuring the PFMs during gait and weightbearing, and to describe PFM electromyographic (EMG) activity during gait with respect to the various weightbearing phases (primary study). **Methods:** We searched 6 databases in August 2014, updated October 2016; and included all human trials that measured the PFMs during gait and weightbearing. Eligible trials were screened by a pair of reviewers. Data was charted to a custom spreadsheet. Based on the results, we designed a descriptive observational primary study including healthy nulliparous female adult volunteers to describe PFM EMG activity during gait. We defined a Base Level of PFM EMG activity in standing – baseline at rest, three maximum voluntary contractions (MVC) (averaged), one submaximal contraction. The maximum uV achieved during the maximum voluntary contractions was normalised as 100%MVC for each subject, with PFM EMG during gait presented as %MVC. Subjects walked freely and easily, 6 times the data capture area. We compared five variables of PFM EMG during gait to describe the impact of weightbearing on PFM activity. Weightbearing phases were derived from motion analysis variables, and indicated time as a % of the gait cycle. PFM EMG was captured with the Periform® electrode (Neen, UK), and synchronised wirelessly (Noraxon) with three-dimensional motion analysis (VICON). **Results:** We identified forty-four studies; all reported on data captured in standing. Four main measurement modalities emerged with many studies reporting on more than one modality – electromyography (55%), pressure (41%), ultrasound (27%) and manual assessment (18%). Most common approach was vaginally, with application via probe. Five studies reported on PFM data gathered during gait or phase thereof. Three studies used surface EMG – two investigated vaginal EMG during running, and one tested the reactions of the striated urethral and external anal sphincters during single-leg stepping in men. Wireless vaginal pressure during walking, running and specified activities was investigated in two studies. Twelve studies investigated PFM function during a variety of weightbearing activities, using EMG and pressure modalities. There is data of PFM function in weightbearing from 1699 subjects; predominantly adult n=1593 (children n=106) and female n=1563 (male n=136). The primary study presented data from eight subjects (age 33,5 ± 8,52 years; BMI 23,98 ± 5,06 kg/m^2). Means and SDs of voluntary PFM EMG during Base Level in standing showed a baseline of 20.25±9.33%MVC; an average of three maximal voluntary contractions of 66.5±6.19%MVC; and a submaximal contraction of 37.875±12.39%MVC. During gait, PFM EMG included double support onto left of 42.375±8.71%MVC; single support on left of 41±16.18%MVC; double support onto right of 39.375±15.20%MVC; and single support on right of 41.75±17.42%MVC. Characteristics emerged during gait; with differences seen in range, amplitude, wave pattern and timing. Subjects showed wide variation, ranging from 20-100%MVC. There was greater inter than intra subject variability. **Conclusion:** Measurements of the PFMs during gait are in their infancy. Involuntary PFM activity exists during walking, and PFM EMG is sensitive enough to identify differences between individual subjects, and between individual limbs within subjects. The development of an electrode capable of differentiating between involuntary activity from various PFMs during gait would improve understanding into the complexity of pelvic function when physically active. PFM measurements made in standing differ from lying. The PFMs are more active, albeit involuntarily, in standing than when non-weightbearing. A disturbance in or disruption to this normal background involuntary PFM activity can cause pelvic dysfunction.

Opsomming

Inleiding: Die bekkenvloerspiere (BVS) dra by tot ingewande beheer, asook blaas, kolon en seksuele funksie. Daar is sterk bewys ter ondersteuning van BBS heropleiding as eerste linie konserwatiewe bestuur van bekkenbodem wanorde. Tot onlangs was navorsing van BBS aktiwiteit en funksie in 'n lêende posisie onderneem vir die gerief van beide proefpersoon en navorser. BVS funksie kan tydens gewigdra en fisiese aktiwiteite ondersoek word te danke aan tegnologiese vooruitgang. **Doelwitte:** Om huidige praktyk te bevestig in die bepaling van die BBS tydens loopgang en gewigdra. Beskrywing van elektromiografiese (EMG) BBS aktiwiteit tydens loopgang met betrekking tot die verskillende gewigdraende fases (primêre studie). **Metodes**: Ses databasisse is deursoek in Augustus 2014 en opgedateer in Oktober 2016. Dit sluit alle menslike proewe in waar die BVS gemeet word tydens loopgang en gewigdra. Toepaslike studies is deur middel van n siftingsproses deur twee beoordelaars identifiseer. Data is op 'n aangemete sigblad saamgebring. Op grond van die resultate, is 'n beskrywende waarnemings- primêre studie ontwerp. Dit sluit gesonde nullipareuse vroulike volwasse vrywilligers in en BVS EMG aktiwiteit word beskryf tydens loopgang. 'n Basisvlak vir bekkenvloerspier EMG aktiwiteit is in staan gedefinieer - basislyn in rus, drie maksimum willekeurige kontraksies (MWK) (gemiddeld) en een submaximal kontraksie. Die piek uV wat tydens elke maksimum willekeurige kontraksies behaal is, is genormaliseer as 100% MWK vir elke deelnemer. Bekkenvloerspier EMG was as %MWK voorgestel tydens die loopgang. Deelnemers het ses keer op hulle gemak oor die data insamelings gebied geloop. Vyf BVS EMG veranderlikes tydens loopgang is vergelyk om die impak van gewigdra op BVS aktiwiteit beskryf. Gewigdra fases is afgelei van beweging analise veranderlikes, en het tydsverloop as 'n persentasie van die loopgang siklus aangedui. Bekkenvloerspier EMG is gemeet met die Periform® elektrode (Neen, Verenigde Koninkryk), en dmv draadloos gesinchroniseer (Noraxon) met 'n drie-dimensionele beweging analiseerder (Vicon). **Resultate**: Vier-en-veertig studies wat rapporteer oor data kolleksie tydens staan is geïdentifiseer. Vier hoof meting modaliteite het na vore gekom - Elektromiografie (55%), druk (41%), ultraklank (27%) en manuele evaluasie (18%). Die mees algemene benadering was vaginaal met 'n meet instrument. Vyf studies rapporteer oor BVS data wat ingesamel is gedurende loop of 'n fase daarvan. Drie studies maak gebruik van oppervlak EMG. Twee van hierdie studies ondersoek vaginale EMG waardes tydens hardloop, en een studie die reaksies van die gestreepte uretrale en eksterne anale sfinkters tydens enkel-been trap in mans. Draadlose vaginale druk is tydens loop, hardloop en spesifieke aktiwiteite in twee studies ondersoek. BVS funksie is met behulp van EMG en druk modalitieite in twaalf studies ondersoek, tydens 'n verskeidenheid van gewigdra aktiwiteite. Data oor BVS funksie tydens gewigdra is beskikbaar van 1699 deelnemers. Die deelnemers was oorwegend volwassenes N = 1593 (kinders n = 106) en vroulike N = 1563 (manlike N = 136). Die primêre studie het agt deelnemers (ouderdom 33,5 ± 8,52 jaar, BMI 23,98 ± 5,06 kg / m2). Gemiddeldes en standaard deviasie van willekeurige BVS EMG tydens die basisvlak in die staan posisie het 'n basislyn van 20,25 ± 9,33% MVC; 'n gemiddeld van drie maksimale willekeurige kontraksies van 66,5 ± 6,19% MVC; en 'n submaximal kontraksie van 37,875 ± 12,39% MVC. Bekkenvloerspier EMG resultate sluit in: dubbel ondersteuning aan die linker kant van 42,375 ± 8,71% MVC; enkele ondersteuning aan die linkerkant van 41 ± 16,18% MVC; dubbel ondersteuning aan die regter kant van 39,375 ± 15,20% MVC; en enkele ondersteuning aan die regter kant van 41,75 ± 17,42% MVC. Daar was verskille gesien in die reeks, amplitude, golfpatroon en tydsberekening tydens loop. Deelnemers het groot variasie getoon wat wissel tussen 20-100% MWK. Daar was 'n groter inter as intra onderwerp variasie. **Gevolgtrekking**: Meting van die BBS tydens gang is in kinderskoene. Onwillekeurige BBS aktiwiteit bestaan gedurende loop. BBS EMG is sensitief genoeg om verskille tussen individuele proefpersone te identifiseer asook verskille tussen individuele ledemate. 'n Versteuring in of ontwrigting van normale onwillekeurige BBS aktiwiteit kan bydra tot pelviese disfunksie. Die ontwikkeling van 'n elektrode in staat om onwillekeurige aktiwiteit te onderskie in BBS tydens gang sal begrip van die kompleksiteit van pelviese funksie tydens fisiese aktiwiteit verbeter.

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Abbreviations and Acronyms

ADLs	activities of daily living
ARA	ano-rectal angle
ASLR	active straight leg raise
BMI	body mass index
CPP	chronic pelvic pain
Diff	difference
DS	double support
EAS	external anal sphincter
EMG	electromyography
ex	exercise
GSI	genuine stress incontinence
Hx	history
IAP	intra-abdominal pressure
ICC	intra-class correlation coefficient
IQR	intra-quartile ranges
ITB	ilio-tibial band
LA	levator ani
LH	levator hiatus
LP	levator plate
M	mean
MDT	multi-disciplinary team
max	maximum
min	minimum
MVC(s)	maximum voluntary contraction(s)
OAB	overactive bladder
PC	pubococcygeus
PFM(s)	pelvic floor muscle(s)
PFMC(s)	pelvic floor muscle contraction(s)
PGP	pelvic girdle pain
PI	primary investigator
POP	pelvic organ prolapse
PR	puborectalis
S*	surface
SD	standard deviation
SS	single support
sub-max	sub-maximal voluntary contraction
SUI	stress urinary incontinence
SUS	striated urethral sphincter
UDS	urodynamic studies
UI	urinary incontinence
Uroflow	uroflowmetry
US	ultrasound
UTI	urinary tract infection
3D	three dimensional

Definitions and Terminology

Bipedal: (of an animal) using only two legs for walking.

Bipedalism: form of terrestrial locomotion where an organism moves by means of its two rear limbs or legs. An animal or machine that usually moves in a bipedal manner is known as a biped meaning "two feet" (from the Latin *bis* for "double" and pes for "foot").

Bilateral: relating to or affecting both sides of an organ, the body, or another structure

Chronic pelvic pain: non-malignant pain perceived in structures related to the pelvis of either men or women.

Locomotion: movement or the ability to move from one place to another.

Pelvic pain syndrome: persistent or recurrent episodic pelvic pain, associated with symptoms suggestive of lower urinary tract, sexual, bowel or gynaecological dysfunction, where there is no proven infection or other obvious pathology.

Quadrupedal: an animal using four feet for walking.

Quadrupedalism: form of terrestrial locomotion in animals using four limbs or legs. An animal or machine that usually moves in a quadrupedal manner is known as a quadruped, meaning "four feet" (from the Latin quattuor for "four" and pes for "foot").

Unilateral: relating to or affecting only one side of an organ, the body, or another structure.

Pelvic floor: relates to the compound structure which closes the bony pelvic outlet.

Pelvic floor muscle(s): refers to the muscular layer of the pelvic floor.

Pelvic floor muscle function: can be qualitatively defined as strong, normal, weak or absent by the tone and the strength of a voluntary or reflex contraction. A pelvic muscle contraction may be assessed by manual assessment (visual inspection and/or palpation), electromyography, perineometry and ultrasound. Factors to be assessed include strength, initiation, endurance, displacement, repeatability and release.

Normal pelvic floor muscles: A situation in which the PFMs can voluntarily and involuntary contract and relax. Voluntary contraction will be normal or strong and voluntary relaxation complete. Involuntary contraction and relaxation are both present.

Pelvic floor muscle dysfunction: A situation in which the PFMs do not function within normal limits.

Overactive pelvic floor muscles: A situation in which the pelvic floor muscles do not relax, or may even contract when relaxation is functionally needed for example during micturition or defecation. This condition is based on symptoms such as voiding problems, obstructed defecation, or dyspareunia and on signs like the absence of voluntary pelvic floor muscle relaxation.

Underactive pelvic floor muscles: A situation in which the pelvic floor muscles cannot voluntarily contract when this is appropriate. This condition is based on symptoms such as urinary incontinence, anal incontinence, or pelvic organ prolapse, and on signs like no voluntary or involuntary contraction of the pelvic floor muscles.

Non-functioning pelvic floor muscles: A situation in which there is no pelvic floor muscle action palpable. This condition can be based on any pelvic floor symptom and on the sign of a non-contracting, non-relaxing pelvic floor.

Pelvic floor muscle disorders: Symptoms associated with PFM dysfunction are divided into five groups – lower urinary tract symptoms, bowel symptoms, sexual function, prolapse, and pain. (7,8)

Chapter One
Introduction

"Bipedalism is the fundamental evolutionary adaptation that sets hominids — and therefore humans — apart from other primates." (1).

1.1. Background

The human pelvis fulfils two main functions – locomotion and childbirth in females. Historically, clinical interest in the pelvic floor muscles (PFMs) is due to the consequences of and for childbirth (2). Trauma to the PFMs during pregnancy and delivery and the subsequent impact on visceral functions, has driven research in bladder, bowel and sexual function in both women and men. The impact of childbirth on the development of pelvic floor disorders is clear, although other contributing factors such as age and obesity play a role (3).

The PFMs are under-recognised for the role they play during gait, or bipedal locomotion. Humans are bipedal. Noted exceptions are usually neurological in nature e.g. delayed persistent crawling in Down's syndrome. Individual variants of quadruped walking have been reported, specifically in the rural areas of Canakkale, Turkey (4), but they are uncommon. For the majority, normal human locomotion is described as bipedal gait. Gait comprises a series of recurring movements that create variable demand in the pelvis; from unilateral weightbearing in single support to weight transfer through the pelvis during double support (5). Bones, muscles, ligaments and tendons develop in response to loading and functional demand (6). This is true throughout the musculoskeletal system. The involuntary action of the PFMs during gait remains unclear.

1.1.1. Pelvic floor muscles

The PFMs form a muscular diaphragm in the pelvic cavity. They consist of many individual muscles; and can be grouped into superficial and deep, anterior and posterior, or left and right; figure 1.1. They have various attachments and are intimately involved with the pelvic fascia (7).

The PFMs function by contracting and relaxing, and are acknowledged as having both voluntary and involuntary activity (7).

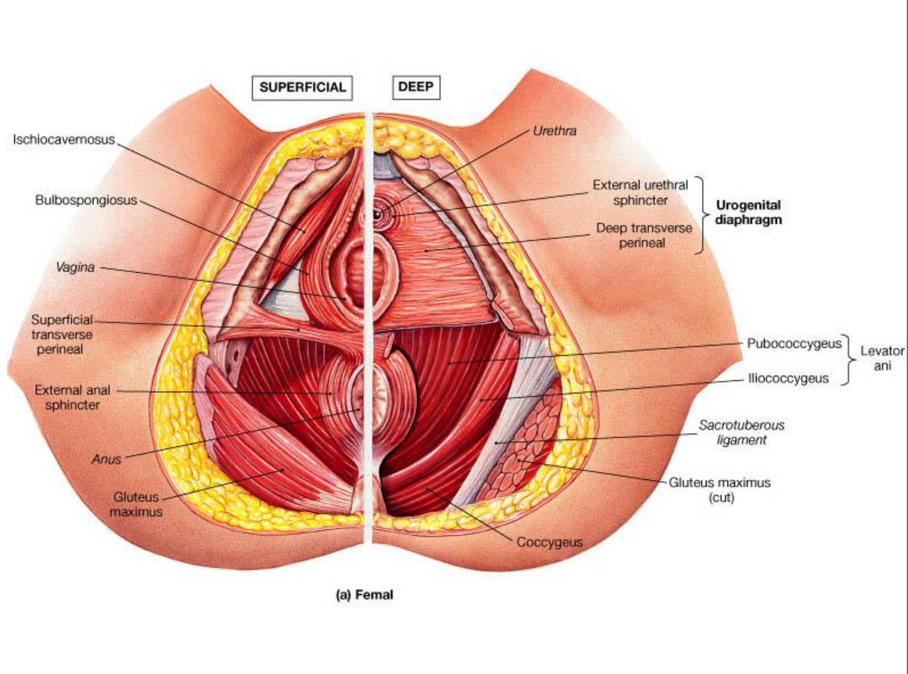

Figure 1-1 Female PFMs[1]; superficial (left) and deep (right)

Standardised terminology[1] of PFM function and dysfunction describes:

- A *voluntary contraction* of the PFMs is that action whereby the patient contracts the PFMs on demand. A contraction is felt as a tightening, lifting, and squeezing action under the examining finger. A voluntary contraction can be absent, weak, normal, or strong.
- A *voluntary relaxation* of the PFMs is that action whereby the patient can relax the PFMs on demand, after a contraction has been performed. Relaxation is felt as a termination of the contraction. The PFMs should return at least to their resting state. A voluntary relaxation can be absent, partial, or complete.
- An *involuntary contraction* of the PFMs is the contraction that occurs preceding an abdominal pressure rise, such as due to a cough, to prevent incontinence. An involuntary contraction can be absent or present.
- An *involuntary relaxation* of the PFMs is the relaxation that occurs when the patient is asked to strain as if defecating. An involuntary relaxation can be absent or present.
- Non-contracting PFMs refer to a clinical finding on palpation, whereby there is no palpable voluntary or involuntary contraction of the PFMs.

This activity is bilateral[2]. Trauma to the PFMs can be bilateral e.g. pregnancy; or unilateral e.g. episiotomy or levator ani avulsion. Trauma can result in PFM dysfunction and associated pelvic floor disorders e.g. bladder, bowel and/or sexual dysfunction. Pelvic floor muscle dysfunction can also result in pelvic pain syndrome or chronic pelvic pain; characterised by persistent or recurrent episodic pelvic pain, associated with symptoms suggestive of lower urinary tract, sexual, bowel or gynaecological dysfunction, in the absence of proven infection or other pathology (8). In such instances, digital palpation is also used to test for pain. Digital pressure on the PFMs may reproduce or intensify the patient's pain. This pain sign can be unilateral[3] (7). Descriptive characteristics of PFM function are found in table 1.1.

Table 1-1 Descriptive characteristics of PFM function

Area	Activity	Length	Effort	Co-ordination	Timing	Tone	Strength	Other descriptors of contraction / relaxation
Superficial / Deep	Contraction / Relaxation	Shortened / Lengthened	Voluntary / Involuntary	Symmetrical / Asymmetrical	Appropriate / Delayed	Normal / High / Low	Gr 0 – 5	Absent / Partial / Weak / Normal / Present / Complete / Strong
Anterior / Posterior	Stable / Erratic	Concentric / Eccentric	Action / Reaction	Bilateral / Unilateral				
Left / Right								

Clinical evidence exists in support of a unilateral response of the PFMs, particularly involuntarily during gait. A recent case report of deep gluteal pain in a 45-year-old female distance runner (competing in one or more marathon per year for 20 years) excluded initial differential diagnoses of

[1] Pelvic Floor Clinical Assessment Group of the International Continence Society (2005)
[2] Bilateral – relating to or affecting both sides
[3] Unilateral - relating to or affecting only one side

i. hamstring syndrome and *ii.* ischio-gluteal bursitis when pain persisted despite intervention. Pelvic floor muscle hypertonic disorder (non-relaxing PFMs) was subsequently diagnosed, and upon revised intervention of soft tissue mobilization to address the increased PFM tone on the left, the pain resolved resulting in return to distance running (9).

Pelvic floor disorders, e.g. urinary incontinence, are directly associated with aging (10), which is known to have a profound impact on PFM cross sectional area, in both parous[4] and nulliparous[5] females (2). Furthermore, obesity is attributed as being a major risk factor for the development of pelvic organ prolapse and incontinence, both urinary and faecal (3). Populations with PFM dysfunction are symptomatic when upright e.g. stress urinary incontinence with coughing in standing; or active e.g. pelvic organ prolapse after being on feet all day. Many pelvic pain populations have pain with weightbearing, and/or during gait and dynamic activities e.g. walking or sport.

Obvious differences exist in the PFMs due to gender dimorphism, figure 1.2. The presence of the middle compartment in females, comprising the vagina with the uterus at its apex, renders the female PFMs more vulnerable to trauma; irrespective of pregnancy and childbirth.

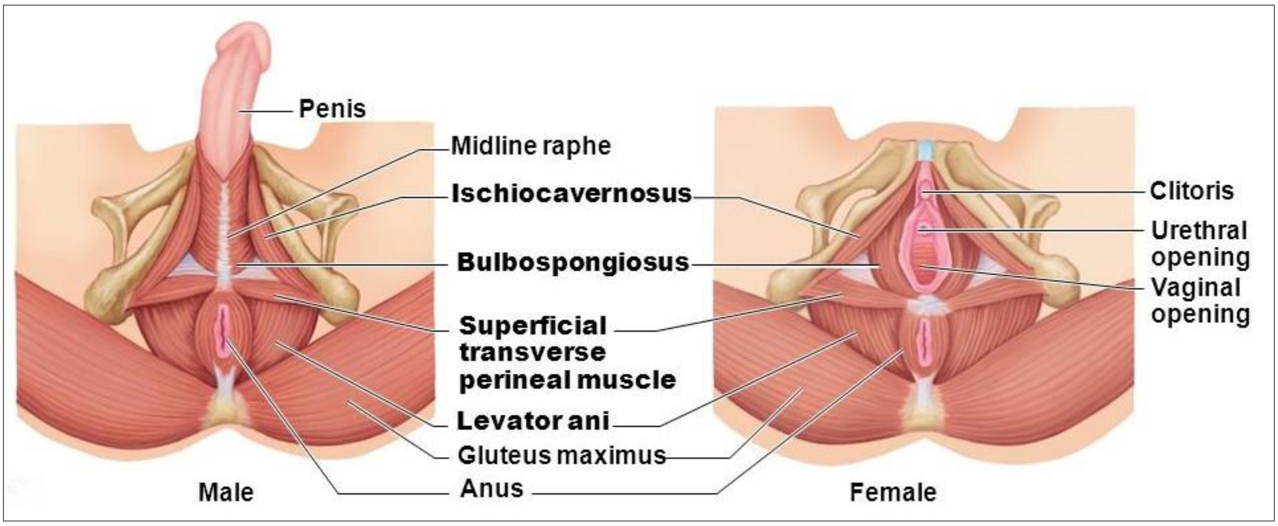

Figure 1-2 Superficial PFMs[6]; male (left) and female (right)

Research into PFM function and activity has traditionally been conducted in non-weightbearing positions; usually lying e.g. supine, crook, prone, side or lithotomy; or sitting. This has been for subject and investigator comfort and convenience. Testing usually relies on the Valsalva manoeuvre to increase intra-abdominal pressure (IAP), or the active straight leg raise (ASLR) to mimic unilateral load through the pelvis. Delayed activation and significantly later onset times of the PFMs during ASLR have been identified in females with pelvic girdle pain, compared to pain free controls (11). Limiting dynamic forces to the ASLR or Valsalva manoeuvre challenges the validity of the findings in extrapolating them to the upright female, who frequently walks, lifts, runs, jumps and coughs, but rarely Valsalva's (12). Although it will always be more convenient to study PFM action when supine, data taken in the upright posture captures the natural action of the muscles in the position in which they function daily (13).

[4] Parous – having had children
[5] Nulliparous – having never been pregnant
[6] Copyright © 2004 Pearson Education, Inc., publishing as Benjamin Cummings Human Anatomy & Physiology, Sixth Edition Elaine N. Marieb PowerPoint ® Lecture - http://slideplayer.com/slide/4445802

1.1.2. Gait and weightbearing

The gait cycle comprises of one full stride revolution through a lower limb, including both stance and swing phases. At times, both lower limbs are in contact with the ground (double support) and at times only one lower limb is in contact (single support).

In figure 1.3, the cycle starts with right heel strike at time zero, or 0% of the cycle. The first double support loads onto the right for 0-12% of the cycle. This is followed by the first single support on the right from 12-50%. The second double support loads onto the left from 50-62%, and the gait cycle is completed by single support on the left from 62-100%.

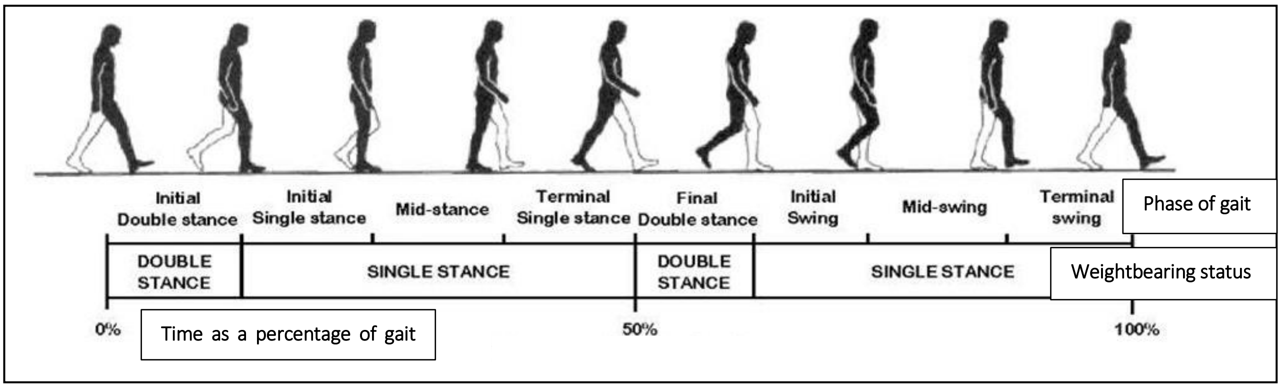

Figure 1-3 Gait cycle relative to right lower limb [7]; time as a %, weightbearing status, phase of gait

There have been a few studies investigating the action and reaction of the PFMs during gait, since 2012. Single leg stepping is a gait similar activity – Stafford et al investigated the activation of the PFMs, specifically the striated urethral and anal sphincters in men during single stepping and reported that PFM activity increases proportionally with intra-abdominal pressure (IAP) (14). They also noted that activity of the PFMs precedes postural adjustment; implying a feedforward mechanism. Gait can be free and unencumbered, but often involves additional load. Shaw et al found statistically significant differences in PFM activity based on walking speed, inclination and load carried (15). Upon assessing the impact of walking and carrying a load of 13.6kg, presumed to represent a baby in a car seat, Coleman et al reported that there is an increase in IAP with walking speed from slow to fast ($p<0.001$), and that subtle variations in speed or carrying method can produce significant changes in IAP (16). Luginbuehl et al tested the reliability of PFM activity and time variables, and validated the use of an internal vaginal electrode (17) during running. Luginbuehl et al also established that all PFM activity parameters are greater during running than they are when performing voluntary contractions in standing (18).

Changes in body position, as found during gait, can affect PFM activity. Results indicate differential PFM activity in standing based on ankle position. Differential ankle positions are experienced during gait. Plantarflexed ankles resulted in a posterior pelvic tilt and a decrease in PFM activity compared with standing with the ankles in a horizontal position; and standing with dorsiflexed ankles facilitated anterior pelvic tilt, which in turn increased effective PFM activity to its greatest point. (19,20). Although no differences were found between horizontal and plantar standing, PFM EMG in dorsal standing was significantly greater than in both horizontal ($p < 0.020$) and plantar standing ($p < 0.040$). (21). Lumbar position is also found to have an impact on PFM activity. Capson et al reported significantly higher resting activity in all postures in standing when compared to supine, and that there was higher resting PFM activity in the hypo-lordotic posture, than in either normal (habitual) or hyper-lordotic postures. Furthermore, subjects generated significantly more PFM activity in their

[7] http://what-when-how.com/pattern-recognition-and-image-analysis/human-recognition-based-on-gait-poses-pattern-recognition-and-image-analysis

habitual posture than they did in either a hypo- or hyper-lordotic posture when performing a maximum voluntary contraction (MVC) or Valsalva, coughing, and load catching (22).

Recent findings indicate that PFM activity is greatest in standing, and that PFM mean resting activity was the lowest in supine and was significantly different compared to standing (p= 0.00024) and sitting (p= 0.0053) (23). Change in levator hiatus area (p=0.003), transverse dimension (p=0.016) and antero-posterior dimension (p=0,003) have been identified between standing and crook lying (24). PFM displacement is greater in standing (25,26). There is less perineal descent in standing, during both squeezing and pushing (p<0.001) and the PFMs are less vulnerable to increasing IAP in standing (27). Furthermore, posture (p=0.000) effects the anterior urethral angle (28) and the ano-rectal angle is more acute in standing (27). This displacement of the PFMs in standing is anterior (24,27,28) and medial (24) in direction. PFM endurance is greater in standing than crook lying (p< 0.001) (26) and some pressures are higher in standing; vaginal resting pressure (25) & vaginal closure force (13). However, vaginal squeeze pressures are lower in standing (25). These changes affect the anterior, middle and posterior compartments of the pelvis. There is a tightening and a shortening in standing compared to lying, rendering the PFMs more resistant to IAP changes in standing.

Standing was found to be a more effective position for achieving and sustaining an elevation of the pelvic floor compared to crook-lying, regardless of sex, and this should be considered when assessing and training PFM contraction (26); although other findings suggest that males use different strategies for activating the PFMs, with 33% of subjects being unable to contract in crook lying; 27% unable to contract in standing, and 11% not able to contract in either position (29).

1.2. Motivation

Walking appears to be a globally acceptable and socioeconomically appropriate method of improving physical activity and overall health. The World Health Organisation (WHO) released an updated fact sheet on physical activity, June 2016. In it they provide guidelines for the recommended amounts of activity by age. They consider walking to be a form of moderate physical activity, alongside cycling and doing sports. Self-paced brisk walking has been shown to correlate with heart rate, as a means of quantifying moderate physical activity (30). Healthy People 2020, an initiative in the United States of America, advises that we increase the proportion of trips made by walking as a means of increasing physical activity in a sedentary population. Walking as a form of physical activity is acknowledged as contributing to health (31) with physical activity deemed essential in combating many chronic diseases associated with lifestyle. Walking is recommended in the management of coronary heart disease, heart failure, intermittent claudication and osteoarthritis of the lower limbs (32). Although the link between chronic disease and walking is not clear due to other contributing factors, interventions to promote walking could contribute substantially towards increasing the activity levels of the most sedentary (33).

Strenuous physical activity has been related to PFM dysfunction (15) and the sporting community is particularly vulnerable with stress urinary incontinence affecting women of all ages including young athletes, especially those involved in high-impact sports (18). Pelvic sports injuries presenting as hip, pelvic or groin pain are evident whilst training or competing, with running identified as a culprit (9). Patients reported persistent postnatal pregnancy-related pelvic girdle pain whilst walking and with other activities of daily living (ADLs) including unilateral weightbearing through the lower limb e.g. standing when dressing, 6 months to one year after delivery (34).

The relationship between pelvic floor disorders and PFM activity is the subject of ongoing investigations. Pelvic patient populations are often symptomatic during upright activity. Smith et al reported greater PFM activation in an incontinent group vs. continent controls, which is contrary to the clinical assumption that incontinence is directly related to weakness and/or reduced PFM activity (35). In a further study into balance, they found that incontinent women have decreased balance ability. They hypothesized that increased PFM activity in incontinent women may impair balance by reducing the contribution of the PFMs to postural control (36).

Non-clinical populations offer further insights. In women who had previously given birth and were without lumbo-pelvic pain, PFM activity during leg and arm lifts was suggestive of a feed-forward response (37); whilst in men striated urethral sphincter activity increased proportionally with IAP. This indicates that the PFMs contribute to continence when intra-abdominal pressure is increased and that postural control of the trunk involves activation of the striated urethral sphincter (14).

Current practise in motion analysis treats the pelvis as a single biomechanical unit, with 3 defined planes of movement – pelvic tilt (anterior posterior), pelvic obliquity (up down) and pelvic rotation (external internal). It is the author's opinion that involuntary unilateral activity of the PFMs occurs during normal gait. A disruption of this normal activity can impact on gait and other pelvic functions, contributing to visceral dysfunction and pelvic pain populations.

As indicated in table 1.1, there are a variety of descriptors for PFM function. However, very little is known about involuntary PFM activity during gait. The aim of this thesis was twofold:

- To establish current practise in measuring the PFMs during gait and weightbearing (scoping review)
- To describe PFM activity during gait with respect to the various weightbearing phases (primary study)

1.3. Study context

This study aims to contribute to the literature by establishing how the PFMs are measured during gait and weightbearing activities, and by investigating and describing PFM activity with respect to weightbearing during gait. It identifies gaps in the literature with a scoping review. Based on the findings thereof, it proposes and conducts a primary study into PFM activity during gait (# IRB0005239; S15/08/170). The research was undertaken at Stellenbosch University, with the primary study conducted at the 3D motion analysis laboratory, Tygerberg Campus. This thesis is intended as a platform for future research into PFM activity during gait and functional whole body movements experienced during dynamic weightbearing activities.

1.4. Thesis Outline

This thesis is presented in article format and consists of four chapters, figure 1.4.

Chapter One comprises the thesis introduction, background, study context, motivation and outline.

Chapter Two is a scoping review, mapping the current practise of measuring the PFMs during gait and weightbearing. The aim was to establish how the PFMs are measured during gait and weightbearing, and to report on modalities, tools and applications thereof. Chapter two is formulated for journal submission following the author publication guidelines for the International Journal of Urogynaecology; Addendum C under the title: "How are the pelvic floor muscles measured during gait and weightbearing? A scoping review." The results were presented under the same title as an oral podium presentation at the International Urogynaecology Association Annual Scientific Meeting 2016, Cape Town, South Africa; Addendum K. This scoping review provided motivation for a primary investigation into PFM activity during gait.

Chapter Three is a primary study, intended for journal submission under the title "A description of the electromyographic activity of the PFMs in healthy nulliparous female adults during the various weightbearing phases of the gait cycle". It was formulated following the author publication guidelines for the International Journal of Urogynaecology; Addendum C, and presents the methodology, results and conclusions of the primary study conducted for the thesis. It is a descriptive study into the activity of the PFMs during gait conducted at the 3D motion analysis laboratory, Tygerberg Campus, Stellenbosch University. The aim of this study was to describe the EMG activity of the PFMs in healthy nulliparous females during the various phases of the gait cycle. This chapter was presented as an *e*poster presentation at the International Urogynaecology Association Annual Scientific Meeting 2016, Cape Town, South Africa; Addendum L. Although originally intended as an article, it was deemed inappropriate for submission to an external examiner due to the specialised nature of the material. Data in Chapter Three is currently presented by subject; this will be amended to a description by weightbearing phase – including range, amplitude, wave pattern and timing – for journal submission. This will synthesise the data, and decrease the number of figures (images).

Chapter Four allows for general discussion of the thesis, including contribution to the literature, clinical implications, strengths and limitations, recommendations for future research and final conclusions.

One complete reference list is presented for the entire thesis for ease of reading. Upon journal submission, individual reference lists will be prepared and included with the appropriate articles.

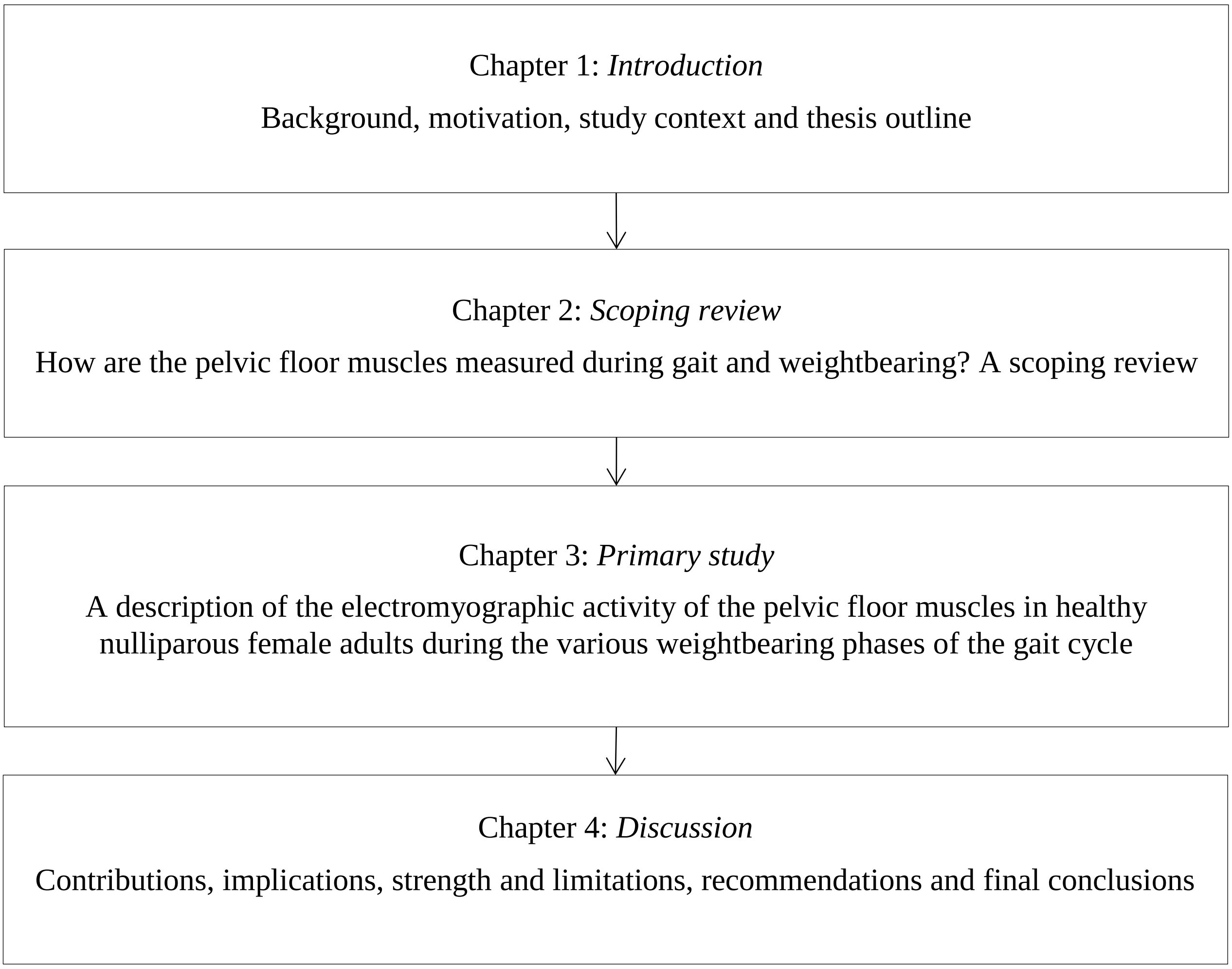

Figure 1-4 Thesis Chapters

Chapter Two
How are the pelvic floor muscles measured during gait & weightbearing? A scoping review of the literature

Corina Avni[1], Ruth Jones[2], Susan Hanekom[1]

Abstract

Introduction and Aim: Pelvic floor muscle (PFM) function during gait is poorly understood. The PFMs are better known for their role in the control of bladder, bowel and sexual function. Their activity during locomotion remains unclear. The aim was to establish how the PFMs are currently measured during gait and weightbearing. **Methods:** We searched *Ebscohost; Pedro; PubMed; Science Direct; Scopus;* and *Web of Science* in August 2014, updated November 2015 and October 2016. We included all human studies that reported on measurements made of the PFMs in weightbearing. Eligible papers were screened by a pair of reviewers. Data was charted to a custom spreadsheet. **Results:** We included forty-four studies; all of which reported on data captured in standing (weightbearing). Five studies (11% of identified research) reported on data gathered during gait or a phase thereof. Of these, three studies used surface EMG – two investigated vaginal EMG during running, and one tested the reactions of the striated urethral and external anal sphincters during single leg stepping. Wireless vaginal pressure during walking, running and specified activities was investigated in two studies. Twelve studies (27%) reported on measurements made during dynamic activities such as ADLs, balance conditions, and a change in ankle or lumbar position. Four main measurement modalities emerged with many studies reporting on more than one modality; they were electromyography (55%), pressure (41%), ultrasound (27%) and manual assessment (18%).The most common approach was vaginally with application via probe. Research spanned twenty-three years, in seventeen countries and across twenty-six specialties. A total of 1699 subjects contributed data; predominantly adult n=1593 and female n=1563, although data exists for males n=136 and children n=106. **Conclusion:** The action and reaction of the PFMs during gait remains unknown.

Keywords: Pelvic floor muscle(s) • Gait • Weightbearing • Standing • Walking • Running

Brief Summary: The PFMs function differently with weightbearing and during gait. This review aims to map the research, describe current practise and identify gaps.

Authors:
Corina Avni – Masters Student, primary investigator, no conflict of interest
Ruth Jones – Clinical Supervisor
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2.1. Introduction

The pelvis of terrestrial mammals provides two major functions; that of locomotion, and in females it serves as the birth canal. Locomotion is defined as the movement of an organism from one place to another. In humans, locomotion refers primarily to bipedal gait or walking, which is an upright weightbearing activity. The significance of weightbearing on human anatomy is well established; bones, muscles, ligaments and tendons develop in response to loading and functional demand (6). Of all the striated muscles in the human body, only the pelvic floor muscles (PFMs) have resting myoelectric activity (38). This activity indicates unique function of the PFMs, as they serve both the visceral and musculoskeletal systems. Like the respiratory diaphragm which is a smooth muscle with both voluntary and involuntary function; so, the striated PFMs have dual action.

The PFMs are involved in more than the control of visceral functions alone. After applying an incremental force to the sacroiliac joints (in cadavers) and using springs to simulate the tension of the PFMs, it was concluded that the PFMs generated a backward rotation of the sacrum in males and females, and have the capacity to increase stiffness in the pelvic ring in females (39). This indicates biomechanical movement within the pelvic ring mediated by the PFMs; with greater demands for stability found in the female pelvis due to the consequences of and for childbirth. Sacral movement (irrespective of gender) and pelvic stiffness (in females) are influenced by PFM activity. Muscles function in response to the loads and forces to which they are subjected (40). A cadaveric study into the architecture of the PFMs found that their design is consistent with muscle sub-specialization (41). By examining the size and volume of the various PFMs, they concluded PFM design shows individual muscles demonstrating differential architecture, corresponding to specialized function in the pelvic floor. Furthermore, they hypothesized functional roles for different PFMs based on their fibre length, and predicted functional sub-specialization.

Changes in PFM activation and function have been identified in chronic pelvic pain populations – men with urological chronic pelvic pain syndrome had more acute ano-rectal angles than pain-free controls. Acute ano-rectal angles correlated positively with greater pain and sexual dysfunction. Anxiety was correlated with more acute ano-rectal angles and more obtuse levator plate angles (42). When PFM outcome measures were tested for their applicability in a female chronic pelvic pain population - women with chronic pelvic pain had higher PFM resting tone and decreased maximal PFM strength and relaxation capacity compared with pain-free controls. Enhanced PFM mechano-sensitivity was also associated with chronic pelvic pain (43).

Pelvic girdle pain (PGP) populations are female, and symptomatic with weightbearing through the pelvis. The published prevalence of PGP varies, but has been estimated at about 45% of all pregnant women and 25% of all women postpartum (44). In 2010, a Norwegian study questioned forty-one sufferers of postnatal pregnancy-related PGP persisting one year after childbirth and found one-third of the women reported that they experienced pain by walking 100 meters, 58% by walking a few hundred meters, and 95% by walking 2 km (34). The impact of PGP on walking is profound. Stuge (2013) found there was a significantly smaller levator hiatus in women with PGP than in controls; at rest, and during automatic and voluntary contractions (45).

Recent findings suggest that disturbed PFM activation influences women's ability to stabilize the pelvis during leg lifts or the active straight leg raise (ASLR) (11,45). Although the ASLR is in non-weightbearing, it mimics walking by applying a unilateral (one-sided) load to the pelvis; hence challenging the PFMs differently from the bilateral activation exhibited during a voluntary PFM contraction for visceral control. Stress urinary incontinence has also been linked to disturbed PFM activation and timing rather than weakness, as demonstrated by PFM EMG and posterior vaginal wall pressure measurements sampled during coughing (46).

The PFMs are well described in the literature. Their role in the control of visceral activity, better known as bladder and bowel function (10,47), is well documented. Research has focused on measurable parameters of PFM function such as strength (48) and power (49); endurance (50);

displacement (51); and timing and activation (52). These are functions of a PFM contraction, and are deemed necessary for continence and for counter-acting the consequences of pregnancy and childbirth. Parameters of PFM contraction and relaxation have been measured using multiple modalities via various approaches with a range of applications. Most of these measurements have been conducted in lying, semi-reclining or seated positions for investigator convenience and subject comfort. Outcomes have informed of PFM function in non-weightbearing positions. Changes in PFM function and activity have been identified in weightbearing positions, and are recognized as having a clinical impact in pelvic pain populations.

Weightbearing increases PFM activity (38). The PFMs contribute to posture (22,27) and balance (36). Bladder volume plays a role in PFM activity, and pelvic dysfunction is co-morbid i.e. incontinence and impaired balance (35). There is very little research that measures the PFMs during gait despite the impact of PFM function on a variety of patient populations and the resultant multidisciplinary interest. Given the extensive literature into PFM function for the control of visceral activity, we wanted to establish what is known regarding PFM activity during gait. Understanding how the PFMs are measured during gait or weightbearing can inform future primary studies. Our aim was to establish how the PFMs are measured during gait and weightbearing.

2.2. Methods

This scoping review followed the methodological framework of Arksey and O'Malley (2005), with additional recommendations for methodological consistency, as described in Levac (53) and endorsed by Daudt (54).

Inclusions were simple and broad to allow for all available literature to be included. Papers were included if they reported on measurements of human PFMs during gait or weightbearing. Conference papers without full texts were excluded. All texts, regardless of language, were deemed eligible. A custom excel spreadsheet was created to extract specific data from the identified studies; Addendum B. Extracted data was randomly checked for accuracy by the primary investigator.

Six electronic bibliographic databases were identified. They were Ebscohost (CINAHL, MEDLINE, SPORTDiscus); Pedro; PubMed; Science Direct; Scopus; and Web of Science. All published literature in peer reviewed journals from database inception were eligible for inclusion, irrespective of study design. The search strategy included terms for the PFMs – "pelvic floor muscle(s)" or "pelvic floor"; in combination with locomotion terms – "gait" or "running" or "walking" or 'jumping" or "standing" or "weightbearing"; Addendum A.

The primary investigator conducted the initial search of databases in early August 2014, updated 25th November 2015 and again 4th October 2016. Review occurred at three levels – title, abstract and full text. A second reviewer reviewed the studies independently. The results of each review were discussed; disputes were carried over to the next level until only full texts which measured the PFMs in weightbearing remained. Studies were assessed using a critical appraisal tool; Addendum F.

The aim was to establish how the PFMs are measured during gait and weightbearing. To meet the aim, the primary objective was to describe the modality, approach (anatomical) and application (technological) of PFM measurements. Secondary objectives were to discuss validity, reliability and feasibility thereof; to report on the weightbearing positions of interest; to discuss the PFMs under investigation and report on the population demographics thereof. In studies measuring the PFMs during gait an additional objective was to describe the methodological approaches including bladder status at testing, establishing a base level and cueing.

2.3. Results

2.3.1. Study selection

The flow chart of the initial search and November 2015 update are shown in the consort diagram; figure 2.1. A total of 582 articles were identified, of which 279 were excluded as duplicates and 164 were excluded at title for not meeting the inclusion criteria, leaving 139 abstracts (and conference papers) for review. Five conference papers were excluded as having no full text manuscript available, and 34 abstracts did not meet the inclusion criteria. One hundred full texts were available for review, of which 56 did not meet the inclusion criteria leaving 44 full texts available for data extraction. One text was in Portuguese, with a full text English translation (55). Seven additional texts were identified in the final update (October 2016); four of which were excluded at abstract, and three at full text.

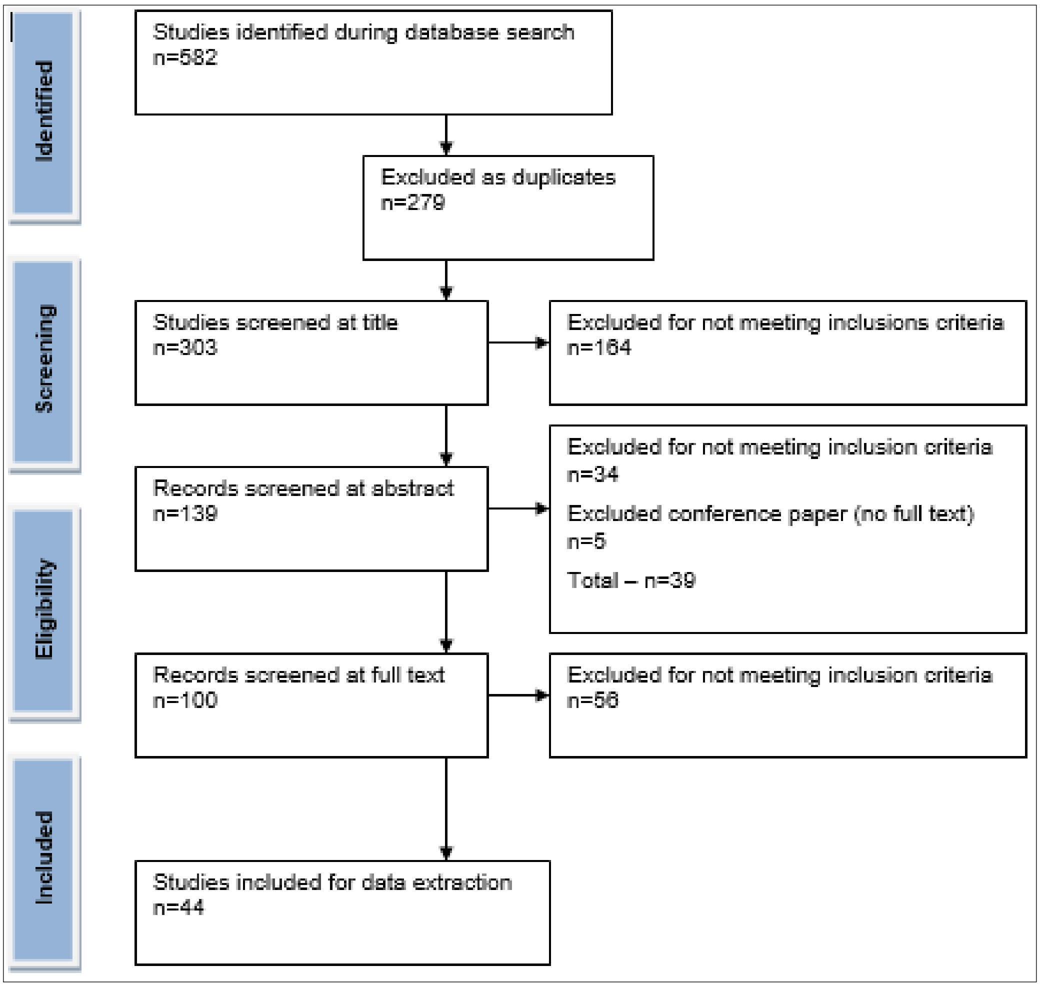

Figure 2-1 Consort diagram

When summarizing the results, three distinct steps were followed (53,54): analysing the data (both descriptive numerical and thematic analyses) and reporting results. The final step of applying meaning to the results is addressed in the discussion.

Data is presented as n= number of studies (% of total research).

2.3.2. Scope of the literature

Forty-four studies have published results of measurements made of the PFMs in weightbearing; the standing position was common to all 44 studies. Four studies have reported on measurements made of the PFMs during gait (15-18) and one during a phase thereof – single leg stepping (14). Twelve studies reported on PFM activity during dynamic activities in weightbearing (14-16,19-22,35,36,56-58).

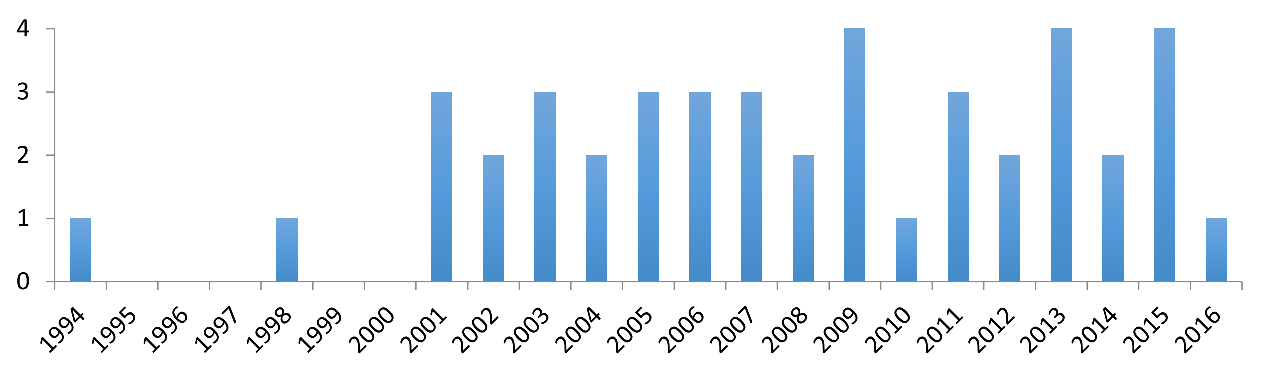

Figure 2-2 Research by year

Research started in 1994 and has occurred in 18 of 23 intervening years; figure 2.2. Twenty-six specialties have contributed to the field; figure 2.3. Much of the research has been multidisciplinary, with ten studies (23%) credited as originating from a single specialty (12,22,26,35-37,46,55,59,60).

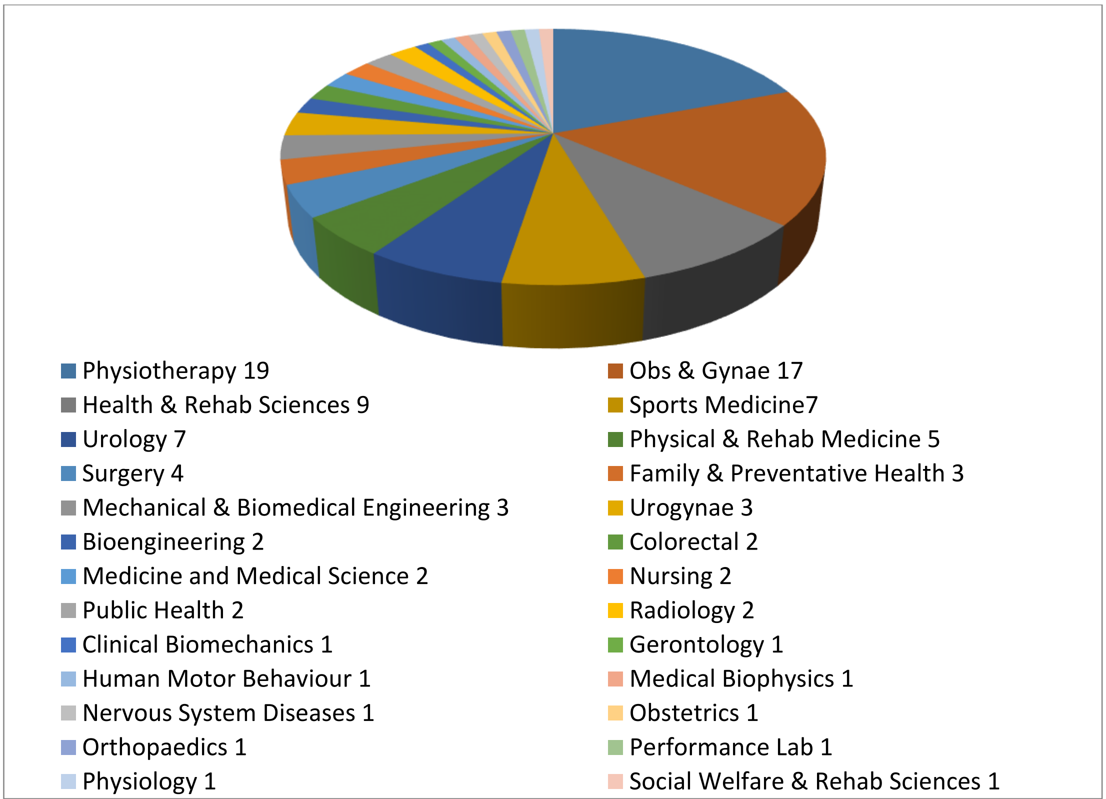

Figure 2-3 Research by discipline

Research has been conducted in seventeen countries and is almost exclusively a first world initiative, with most activity in Europe, North America and Australia. Many studies have seen multi-centre collaboration. Figure 2.4 is a world map of research geographically.

The body of literature comprises of exploratory, investigatory, descriptive and comparative studies, alongside feasibility and reliability testing. Interest comes from many academic and clinical backgrounds. The diversity of the literature was marked; various weightbearing positions were used to investigate a range of PFM activities. Different measurement modalities reported on different aspects of the PFMs and their functions. There was no consistency in sampling or methodologies bar the tendency for many studies (particularly EMG and pressure) to establish a base level prior to commencing the test procedure; table 2.1 lists the causes of research heterogeneity.

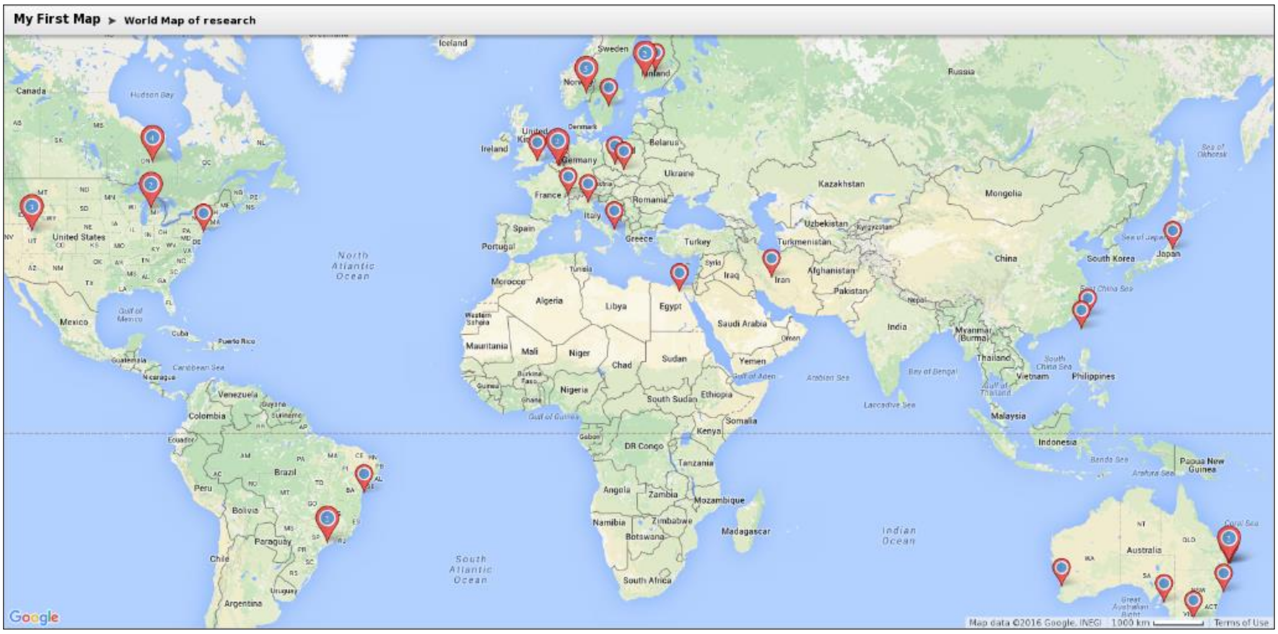

Figure 2-4 Research geographically

Table 2-1 Causes of heterogeneity

Clinical	Methodological
Gender (male vs female)	Measurement with different modalities
Age (child vs adult)	Measurement of different structures
Health status (healthy vs pelvic dysfunction)	Measurement in different positions
Parity (nulliparous vs parous)	Measurement during different activities
Menopausal status (pre vs. post)	Differences in bladder filing conditions
	Differences in units of measurement EMG in µV or %; pressure in N or cmH_2O or mmHg; US in metric (cm or mm) or degrees
	Differences in analysis

2.3.3. Population demographics

Populations varied widely. Sample sizes ranged from n=4 to n=163; average n=39. A sample across all studies resulted in a total of n = 1699 (n = 1712 at initial sampling; n = 1699 at one year drop out). The youngest subject was 3 years old and the oldest was 88 years. Females have been investigated more than males by a ratio of more than 11:1; and adults more than children by a ratio of almost 23:1; figure 2.5.

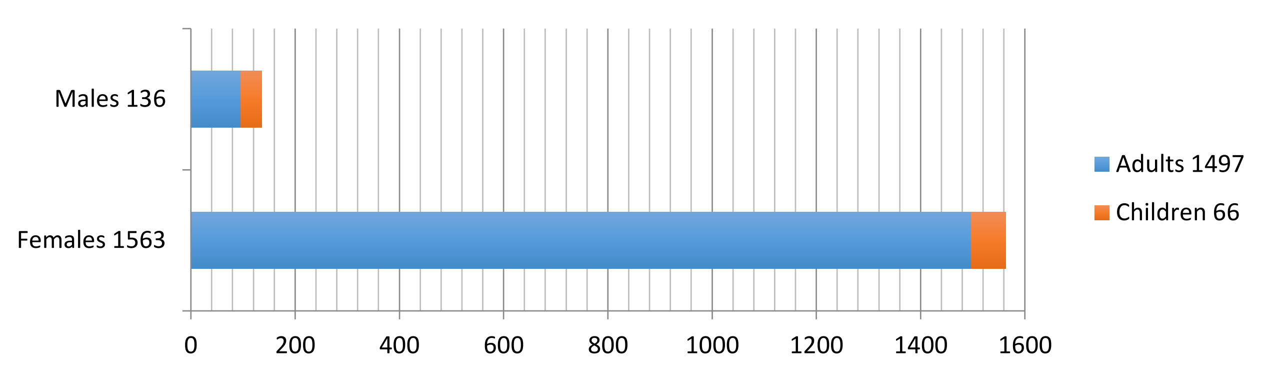

Figure 2-5 Gender and age of subjects

There were 2 paediatric studies; both of which examined changes in PFM activity brought on by position. One used uroflowmetry and ultrasound (US) to establish normative PFM values between supine and standing in 11 girls and 10 boys aged 7-16 (61); the other used uroflowmetry and EMG to assess the impact of position on urination in 55 girls and 30 boys ages 3-14 (57). Paediatric subjects (n=106; 6%) are in the minority when it comes to pelvic research compared with their adult counterparts (n=1593; 94%).

Most of the studies are in peri-menopausal women, but there was wide variability, and no common age range. In adults, three studies sampled from both genders. Two studies reported on healthy subjects; one investigated six women and one man (age 35-63, M 45.7) to describe the contraction of the PFMs during abdominal manoeuvres (62), and the other sampled 45 women 20 men (average age 23, SD 3) to establish differences in PFM function between positions and genders (26). The only mixed gender study in a dysfunctional population investigated sixty-three constipated subjects; 51 women and 12 men (age 28-79, M 58, SD 15) and aimed to describe the contribution of posture to the maintenance of faecal continence (27).

2.3.4. Measurement modality, approach and application

Measurements made of the PFMs during standing – modality, approach and application; table 2.2. Measurements made of the PFMs during gait – modality, approach, application, PFMs, population, bladder status, cuing, Base Level, and reliability and feasibility; table 2.3. Measurements made of the PFMs during dynamic activities – modality, approach, application, PFMs, population, and bladder status; table 2.4.

Four main measurement modalities emerged; electromyography (EMG), pressure, ultrasound (US) and manual assessment. The anatomical approaches included internal (urethra, vaginal, ano-rectal or intra-abdominal); perineal; trans-perineal and trans-abdominal. The most common application was via probe because multiple measurement modalities refer to their instrument as a probe (EMG, pressure and US). Surface EMG was more widely used than fine wire EMG. Catheters and balloons were commonly used in pressure measurements, although recent studies are utilising wireless technology both in and out the laboratory. Uroflowmetry and urodynamic studies are pressure applications in themselves. All applications require a degree of technology, except for manual assessment.

Eighteen studies used other equipment to gather additional pelvic data or to create specific research conditions (12,16-20,22,27,36,38,46,56,59,63-67). Apparatus such as the treadmill (17,18), tilt table (38,59), adjustable platforms (19) and wooden blocks (20) were used to create specific research conditions, whilst motion related data was gathered from accelerometry (17), inclinometry (36) and motion analysis (22). Other assessment tools included biofeedback (56,65,66), questionnaires (16,64,67), a pad test (63) and peak respiratory flow rate (46). Fluoroscopy (12), static proctography (27) and colour Doppler (12) provided other imaging insights. There were no magnetic resonance imaging (MRI) studies that met the eligibility criteria.

All the measurement modalities used are valid and have had reliability testing performed, albeit in non-weightbearing positions. Discriminative validity of a clinical evaluation was established (68); and a wireless intra-vaginal pressure probe with known criterion validity was investigated for reproducibility during dynamic activities (15). Reliability studies identified included the reliability of the aforementioned clinical evaluation (visual inspection and manual assessment) in continent and incontinent women (68); an intra-therapist, intra- and inter-session reliability test for manual assessment and vaginal manometry based on position (supine, crook lying, sitting and standing) in a mixed group of women (25); a test re-test reliability study of PFM contractions with four dimensional US in a mixed group of women (69); optimal cueing instruction for a PFM contraction with two dimensional US in pre-menopausal nulliparous continent women (28); the impact of different body positions on PFM EMG reliability in nulliparous continent women (23); an intra-session test-retest reliability of PFM EMG and time variables during running in healthy nulliparous women (17); and an investigation into the reliability of PFM EMG during different running speeds in healthy nulliparous women (18). Feasibility studies made use of wireless technology; with IAP being investigated during dynamic activities (15) and during walking and carrying (16) in healthy women via a small intra vaginal wireless probe.

2.3.5. Weightbearing positions

Standing was common to all forty-four studies i.e. no studies reported on measurements made during gait or dynamic activities without reporting on data gathered in standing; table 2.2. As a weightbearing activity, standing occurs through both lower limbs simultaneously. Data gathered from more than one testing position was common; only three studies reported on measurements made in standing alone (24,69,70).

Five studies reported on measurements made of the PFMs during gait or a phase thereof; table 2.3. Three studies used surface EMG; two reported on vaginal EMG during running (17,18); and one study investigated striated urethral sphincter and external anal sphincter activity during single leg stepping (14). Two studies used wireless intra-vaginal pressure, one during walking & carrying (16) and one during walking and running amongst other activities (15). All gait studies were in healthy individuals; tested on an empty bladder; and established a base level of PFM activity in standing before commencing with their respective test procedures. Four studies were in females, and one study investigated male PFMs (14). Cueing during gait studies was verbal, whilst the single leg stepping study used both verbal and visual cueing (14). The two EMG studies during running established reliability of an internal vaginal electrode (17,18), whilst the two pressure studies investigated feasibility of the wireless vaginal device, both in (15) and out (16) the laboratory.

Dynamic activities were deemed relevant as impacting on PFM function and were investigated in twelve studies; table 2.4. Three of the studies reporting on gait also investigated other activities (14-16). Seven studies used surface EMG only (14,19-21,35,36,56). Five used the vaginal application thereof (19,20,35,36,56), one looked at the striated urethral and anal sphincters (14), and another assessed the PFMs via perineal EMG (21). Between them they investigated a change in ankle position (19-21); catching (14,35) and arm movements in standing (14); ADLs (56) and balance conditions (36). Two studies used both surface EMG and pressure – one investigated the impact of modified squat & on toes (57) on perineal EMG and uroflowmetry; the other described vaginal EMG and pressure during a change in lumbar position (22). Three studies used wireless vaginal pressure probes to describe PFM function during a variety of activities including carrying (16); cycling, dusting, lifting, moving, scrubbing, and stretching (15) as well as the impact of a range of Pilates exercises on the PFMs (58). There was a wider range of population demographics when reporting on measurements made during dynamic activities. One paediatric study looked at PFM function with lower urinary tract dysfunction in both boys and girls (57). The remainder were adult studies, and all female aside from one male study (14). Five studies specified healthy subjects (14-16,20,58); two specified continence (22,36), one of which compared continence with incontinence (36) and a further four investigated in incontinent populations (19,21,35,56). Seven studies specified an empty bladder at time of testing (14-16,22,35,36,58); of which two also tested with the bladder at a sensation of moderate fullness (35,36); the children needed full bladders to void (57); and four did not state or specify bladder volume at testing (19-21,56).

2.3.6. Pelvic floor muscles under investigation

When reporting on the PFMs, three descriptive categories or classifications emerged in the research:

- Non- specified 'PFMs' – reported on the group of muscles as a whole (single entity)
- Specified PFMs – identified and isolated
- Surrogates of the PFMs – anatomically distinct non-muscular markers of PFM activity and/or function

Twenty-four studies (55%) reported on measurements made of the PFMs as a single entity (17-23,25,35-37,46,55-57,59,60,64-67,70-72). They were mostly EMG and/or manual assessment studies.

Five studies identified specific PFMs namely: pubococcygeus (27,62,68); levator ani (38,68); the external anal sphincter (14,62); the striated urethral sphincter (14) and puborectalis (27).

Changes to measurable anatomical features correlate with PFM activity and function (73,74). Twenty-three studies (52%) reported on surrogates of the PFMs, based on anatomical and functional markers. There were fifteen surrogates in total. Ultrasound and pressure modalities tended to use PFM surrogates in capturing and quantifying data of PFM activity and function. Surrogates of the PFMs include vaginal pressure (15,16,22,46,58,60,64) and walls (13,75); the bladder neck (12,61,63,67,69,76), base (26,29,77) and pressure (13,71); the urethra (28,57,63,76), urethral pressure (71) and retro-vesical angle (12); the ano-rectal angle (27,63,76), rectum (69) and rectal pressure (38,71); the levator hiatus (24,69) and plate (69); perineal descent (27) and the cervix (69).

2.4. Discussion

This review has fulfilled the mandate "to map the literature on a particular topic or research area and provide an opportunity to identify key concepts; gaps in the research; and types and sources of evidence to inform practice, policymaking, and research" (54). A limitation of scoping studies in general is that they identify what issues researchers addressed, but are not able to provide the answers presented by the research (54). This review has established current practise in measuring the PFMs during gait and weightbearing. It has identified measurement modalities, approaches and applications. However, it has not reported on the findings of PFM function during gait and weightbearing presented in the literature.

Four main measurement modalities emerged, and technologies appropriate for use in the pelvis during gait and dynamic activities were identified. We highlighted how little is known about PFM function during gait or weightbearing, and emphasised the bias of research in favour of the female adult pelvis. We identified the range of clinical interest into pelvic function and its impact on multiple pelvic populations.

2.4.1. Gait, dynamic activities and weightbearing

The weightbearing positions under investigation indicate where clinical interest lies. Patients with pelvic dysfunction (urinary incontinence and pelvic organ prolapse) are invariably symptomatic with upright activities. Standing, as a weightbearing activity, involves simultaneous bilateral activity through the pelvis – both sides are doing the same thing at the same time. Gait however involves alternate unilateral activity through the pelvis – single support results in one side in stance phase (weightbearing) whilst the other side is in swing phase (non-weightbearing). Dynamic activities introduce further variables, be they exogenous (16,18) (speed, inclination, loading) or endogenous (14,46) (pressure changes like coughing and catching). Electromyography and pressure were the two modalities that have attempted to describe activity of the PFMs during gait and dynamic activities.

2.4.2. PFMs and professional scope

Professional scope or scope of practise can be described as the procedures, actions, and processes that a healthcare practitioner is permitted to undertake in keeping with the terms of their professional license, or the extent and limits of the medical interventions that a health care provider may perform. Many disciplines come together in the pelvis. The PFMs are not a single unit, but are comprised of multiple muscles, with varied origins, insertions and excursions. Specific roles for the various PFMs have been hypothesized (41); be it for the generation of pelvic girdle forces as experienced during gait (39); or intra-pelvic forces as experienced during coughing (76). With the MAPLe probe (Multiple Array Probe Leiden), differences are seen in anal EMG based on gender, and vaginal EMG in females based on age, parity and menopausal status. In addition, significant differences are seen between the left and right sides of the PFMs at rest and during maximal voluntary contraction (MVCs) and endurance in vaginal measurements in women (78). The PFMs don’t work in isolation but are intimately involved with the fascia in the area (79), which divides the pelvis between functional specialties – urinary function anteriorly (urologists and urogynaecologists), sexual function latero-ventrally in females (obstetricians & gynaecologists and urogynaecologists), with bowel function posteriorly (gastroenterologists and colorectal surgeons). Whether establishing normal function, investigating differences in function between positions or populations, or comparing the impact of a change in conditions on PFM function, the clinical interest was wide-ranging – from physio to Obs & Gynae; colorectal to clinical biomechanics; nervous system diseases to nursing. The PFMs fulfil both musculoskeletal (weightbearing & locomotor functions) and musculovisceral (bladder, bowel & sex function) functions in the pelvis.

2.4.3. Inaccessibility of the area

The PFMs are difficult to assess and measure, in part due to technology, in part due to subject comfort or investigator convenience. Measurements in the pelvis are difficult, for a variety of bio-psycho-social reasons, and gathering data of pelvic function is challenging. This might have weighted the current paradigm of PFM function by providing extensive evidence in convenient positions which hasn’t necessarily informed of function in weightbearing. Whilst research has been conducted in non-weightbearing positions “limiting dynamic forces to a Valsalva manoeuvre challenges the validity of the findings in extrapolating them to the upright female, who frequently walks, lifts, runs, jumps and coughs, but rarely Valsalva’s” – Dr HP Dietz (12).

With the advent of newer technology, wireless options have allowed EMG and pressure to disconnect the subject from the bulk of the measurement equipment, allowing for a small receiver to transmit data from the subject to the modality mainframe. This is increasingly seen in the research, as dynamic activities are investigated both in and outside the laboratory. Technology is increasingly enabling the creation of specific conditions in the laboratory, and the ability to monitor real-life conditions beyond its walls. However, due to the challenges of retaining devices in the pelvis during dynamic weightbearing activities, the data gathered from these studies is limited. Firstly, EMG does not differentiate between concentric (shortening) and eccentric (lengthening) activity, nor do the current electrode options for use in weightbearing differentiate between left and right, or superficial and deep. The MAPLe probe provides insight into unilateral PFM function, albeit in non-weightbearing position (78). Whilst pressure options are increasingly able to differentiate between lower and upper vaginal pressures (presumed to be indicative of the PFMs and intra-abdominal pressure respectively), they also fail to differentiate between left and right. Other measurement modalities, like ultrasound and manual assessment, are not viable options during functional whole body dynamic movements due to the absence of stable reference points.

2.4.4. Strengths and limitations

To the best of our knowledge, this is the first scoping review establishing current practice of measuring the PFMs during gait and weightbearing. The extent of this review is evident in the variety of identified literature, and can be viewed as a strength in that it highlights the gaps in the research, upon which clinical practice is based.

There are limitations. The search sought to identify gait related studies, although was extended to include weightbearing. An even wider search may have yielded more results, including sports specific terminology; “postural control”; and involuntary, automatic or reflex contraction. As studies were descriptive, observational or investigative in nature, sources of bias could not be established. The heterogeneity of the included material dictated a descriptive analysis, excluding a systematic review of the research. The scope was broad, and additional information regarding study design, methodological approaches, and bladder status at testing could not be included at article level, but are available as part of a larger study.

We have terminology (7) to describe and quantify PFM function based on:

- contraction and relaxation (bilateral concentric activity based on voluntary action)
- voluntary and involuntary (bilateral concentric and eccentric activity based on action and reaction)

We need terminology that accounts for:

- bilateral vs. unilateral activity (simultaneous action vs. alternate reaction and left from right)
- PFM sub specialization (front from back; superficial from deep; musculoskeletal from musculovisceral)

There are gaps in the literature. We need to establish normative values (ranges of normal for specified measurable parameters) of PFM function in standing for distinct pelvic populations (male vs female; adult vs child). The impact of weightbearing on PFM function needs to be described, as does the action and reaction of the PFMs during gait.

2.4.5. Recommendations

We recommend further studies during upright dynamic activities, to establish the impact of weightbearing and functional whole body movements on involuntary activity of the PFMs. We further suggest that establishing a paradigm of normal PFM function in different populations (based on gender, age, parity, hormonal status) will allow for enhanced treatment specificity. Given the current treatment protocols, including outcomes for pelvic surgery in an ambulatory population, we need to understand how the PFMs function during normal human gait.

2.4.6. Conclusion

Two options emerged for measuring the PFMs during gait or dynamic activities; EMG and pressure. Wireless technology has recently allowed for greater study subject freedom, both in and out the laboratory. When standing on both legs at the same time, US and manual assessment offered additional insights. Weightbearing, with simultaneous activity through both lower limbs, should be differentiated from gait or dynamic activities, which rely on the alternate use of left and right lower limbs.

Table 2-2 Measurements made of the PFMs during standing

STUDIES	MODALITY				APPROACH ANATOMICAL						APPLICATION TECHNOLOGICAL								OTHER OPTIONS		
	EMG	Pressure	Ultrasound	Manual assessment	Vaginal	Anal / Rectal	Perineal	Intra-abdominal	Trans-abdominal	Trans-perineal	Surface	Fine wire	Probe / speculum	Catheter / balloon	Palpation	Visual	Uroflowmetry	Urodynamic Studies	Fluoroscopy	Static Proctography	Colour Doppler
(55) Rett 2005	√				√						√		√								
(23) Chmielewska 2015	√				√						√		√								
(65) Aukee 2003	√				√						√		√								
(66) Aukee 2004	√				√						√		√								
(37) Sjodahl 2009	√				√						√		√								
(70) Ptaszkowski 2015	√				√						√		√								
(38) Shafik 2003	√					√	√	√				√		√							
(60) Madill 2008	√	√			√			√			√		√	√							
(46) Madill 2010	√	√			√			√			√		√	√							
(59) Neumann 2002	√	√			√			√			√			√							
(62) Sapsford 2001	√	√			√	√					√		√								
(71) Mayer 1994	√	√		√	√						√				√			√			
(25) Frawley 2006		√		√	√								√		√						
(64) Gameiro 2013		√		√	√								√		√						
(13) Morgan 2005		√			√								√								
(72) Bo 2003		√			√									√							
(75) Frawley 2006		√	√	√	√				√				√		√						
(67) Meyer 1998		√	√	√	√					√			√		√			√			
(12) Dietz 2001		√	√							√			√					√	√		√
(76) Peng 2007			√	√	√					√			√		√						
(63) McLean 2013			√	√	√					√			√		√						
(61) Bower 2006			√						√				√				√				
(29) Scott 2013			√						√				√								
(26) Kelly 2007			√						√				√								
(77) Arab 62			√						√				√								
(28) Crotty 2011			√							√			√								
(24) Bo 2009			√							√			√								
(69) Braekken 2009			√							√			√								
(68) Devreese 2004				√	√										√	√					
(27) Altomare 2001						√														√	

Table 2-3 Measurements made of the PFMs during gait

STUDIES	GAIT				MODALITY		APPROACH ANATOMICAL			APPLICATION TECHNOLOGICAL		PFMs				POPULATION			BLADDER STATUS	CUEING		BASE LEVEL	RELIABIITY FEASBILTY	
	Walking	Running	Stepping	Jumping	EMG	Pressure	Vaginal	Urethral	Anal	Surface	Wireless	Non-specified PFMs	Striated Urethral Sphincter	External Anal Sphincter	Surrogate – Vaginal Pressure	Women	Men	Healthy	Empty	Verbal	Visual	Established	Reliability	Feasibility
(14) Stafford 2012			√		√			√	√	√			√	√			√	√	√	√	√	√		
(17) Luginbuehl 2013		√			√		√			√		√				√		√	√	√		√	√	
(18) Luginbuehl 2016		√			√		√			√		√				√		√	√	√		√	√	
(15) Shaw 2014	√	√	√	√		√	√				√				√	√		√	√	√		√		√
(16) Coleman 2015	√					√	√				√				√	√		√	√	√		√		√

Table 2-4 Measurements made of the PFMs during dynamic activities

STUDIES	DYNAMIC WEIGHTBEARING ACTIVITIES															MODALITY		APPROACH ANATOMICAL				APPLICATION TECHNOLOGICAL			PFMs				POPULATION						BLADDER STATUS			
	ADLs	Arm Movements	Balance conditions	Carrying	Catching	Change in ankle position	Change in lumbar position	Cycling	Dusting	Lifting	Modified Squat/On toes	Moving	Pilates Exercise	Scrubbing	Stretching	EMG	Pressure	Vaginal	Urethral	Anal	Perineal	Surface	Wireless	Uroflowmetry	PFMs	Striated Urethral Sphincter	External Anal Sphincter	Vaginal Pressure	Female	Male	Healthy	Continent	Urinary Incontinence	Lower Urinary Tract	Empty	Moderate fullness sensation	Full	Not stated
(56) Aukee 2002	√															√		√				√			√				√				√					√
(19) Chen 2005						√										√		√				√			√				√				√					√
(20) Chen 2009						√										√		√				√			√				√		√							√
(35) Smith 2007					√											√		√				√			√				√				√		√	√		
(36) Smith 2008			√													√		√				√			√				√			√	√		√	√		
(14) Stafford 2012		√			√											√			√	√		√				√	√			√	√				√			
(21) Cerruto 2012						√										√					√	√			√				√				√					√
(57) Furtado 2014											√					√	√				√	√		√	√				√	√				√			√	
(22) Capson 2011							√									√	√	√				√			√			√	√			√			√			
(16) Coleman 2015				√													√	√					√					√	√		√				√			
(58) Coleman 2015													√				√	√					√					√	√		√				√			
(15) Shaw 2014								√	√	√		√		√	√		√	√					√					√	√		√				√			

Chapter Three
A description of the electromyographic activity of the pelvic floor muscles in healthy nulliparous female adults during the various weightbearing phases of the gait cycle

Corina Avni[1], Ruth Jones[2], Susan Hanekom[1]

Abstract

Introduction and Aim: Pelvic floor muscle (PFM) activity for the control of bladder bowel and sexual function is well researched, and strong evidence exists in support of PFM retraining for the management of pelvic floor disorders. To date there have been almost no studies measuring the PFMs during normal human locomotion, or gait. The aim of this study was to describe the EMG activity of the PFMs in healthy nulliparous female adults during the various weightbearing phases of the gait cycle. **Methods:** A descriptive observational study including healthy nulliparous female adults to describe PFM activity during the various weightbearing phases of the gait cycle. We define a Base Level of PFM activity in standing, equating the highest uV achieved during a maximal voluntary contraction with 100%MVC per subject. We then compare five variables of PFM EMG activity during gait to describe the impact of weightbearing on the PFM activity as %MVC. Weightbearing phases are derived from four time-based motion analysis variables. **Results:** Our sample comprised eight subjects – age 33,5 ± 8,52 years; BMI 23,98 ± 5,06 kg/m^2. Means and SDs of PFM EMG during Base Level showed a baseline of 20.25±9.33%MVC; an average of three maximal voluntary contractions of 66.5±6.19%MVC; a sub-maximal contraction of 37.875±12.39%MVC. Data captured during gait included – double support onto left 42.375±8.71%MVC; single support on left 41±16.18%MVC; double support onto right 39.375±15.20%MVC; and single support on right 41.75±17.42%MVC. Subjects showed wide variation of PFM EMG as a %MVC, ranging from 20%MVC to over 100%MVC. There was greater inter than intra subject variability, indicating individuals use specific strategies of involuntary PFM activity during gait. A distinct wave pattern of PFM EMG emerged during gait; PFM EMG decreased during double support, increased to a peak during single support, before decreasing again into double support. **Conclusions**: PFM activity during gait showed wide variability of range, amplitude and wave pattern between subjects, indicating that wireless EMG is sensitive enough to detect individual variations. Variable PFM activity strategies during weightbearing are evident in the differences between left and right wavelengths. Potential cross talk or motion artefact, and the representation of the PFMs as a single unit, should limit the interpretation of these results.

Keywords: Pelvic floor muscle(s) • Gait • Walking • Weightbearing • Electromyography • Involuntary • Unilateral

Brief Summary: EMG of the PFMs during gait is sensitive enough to show a distinctive pattern of involuntary activity, with individual variations in range, amplitude, wave pattern and timing.

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3.1. Introduction

The duality of pelvic function presents challenges for patients, clinicians and researchers alike. Pelvic requirements for locomotion and childbirth are opposing forces – one requiring stability for weightbearing, the other flexibility for delivery. Pregnancy and childbirth have an impact on the PFMs; evidenced by the prevalence of pelvic disorders in parous women including bladder, bowel and sexual dysfunction (2,3). Parturition[3] marks a transition from predominantly involuntary PFM activity, to varied levels of voluntary PFM activity in a bid to retain visceral control – bladder, bowel and sexual function. First line conservative management includes PFM retraining for many pelvic floor disorders – namely stress urinary incontinence, overactive bladder, pelvic organ prolapse, and faecal incontinence, (80,81). The PFMs are also recognised as playing a role in spinal control with overactive PFMs associated with pain presentations (11,45,82,83). Whilst the impact of childbirth on the pelvis and PFMs, and its association with pelvic floor disorders, is well researched and documented (2,3) the same cannot be said for the locomotor function of the pelvis, and any associated involuntary PFM activity during gait.

Normal human gait comprises of a series of recurring movements. Recurring movements in the pelvis include translation and rotation (5,84). Translation is described as vertical and lateral displacement; whilst rotational movements include pelvic rotation (one lower limb in front; one lower limb behind) and pelvic tilt (one lower limb up; one lower limb down). During non-weightbearing, an active straight leg raise (ASLR) is often used to load the pelvis unilaterally to mimic the action of gait. Involuntary PFM activity occurs during the ASLR in women with and without pelvic girdle pain (45). Sjodahl et al reported significantly later onsets of PFM activity during the ASLR in women with pelvic girdle pain compared to pain free controls (11).

Measurements of the PFMs made during gait are in their infancy – five studies report on data of involuntary PFM activity captured during gait or a phase thereof. Luginbuehl et al (17,18) used PFM EMG to test reliability of an internal vaginal electrode during running, and subsequently to describe periodic characteristics of PFM EMG during running. Stafford et al (14) also used EMG, although they described striated urethral and anal sphincter activity in men during single leg stepping, arm movements and load catching. Shaw et al (15) and Coleman et al (16) investigated feasibility of a wireless internal vaginal probe both in and out the laboratory, for monitoring intra-vaginal pressure. These studies do not differentiate between individual or groups of PFMs; they provide data from the PFMs as a single unit.

The Multiple Array Probe Leiden (MAPLe probe) can differentiate between the left and right sides of the PFMs. Voorham-van der Zalm et al assessed 229 healthy volunteers (males n=61; nulliparous[4] premenopausal females n=86; parous[5] premenopausal females n=37; nulliparous postmenopausal females n=5; parous postmenopausal females n=40) during five tasks – at rest, maximum voluntary contractions, endurance, cough, and Valsalva. They reported significant differences in PFM EMG activity between left and right sides. The probe was sensitive enough to identify differences in PFM EMG based on the population groupings. However, due to dimensions it is not appropriate for use in upright positions (78).

Crosstalk is a limitation of all EMG. Motion artefact needs to be minimised, due to probe movement in the vagina during testing. Although there is no gold standard, the Periform®, a pear-shaped electrode measuring 7.5cm:3.4cm, with two recording electrodes of 3.5cm:1.5cm located laterally and generating a single signal was our best option at present. A vaginal EMG probe should be designed that is easy to insert (does not stretch the introitus), has close together electrode surfaces to provide differential signals, and does not move with respect to the vaginal wall during functional tasks. (87).

[3] Parturition – giving birth to young
[4] Nulliparous – having never been pregnant
[5] Parous – having had children

A case report of deep gluteal pain in a 45-year-old female distance runner (competing in one or more marathon per year for 20 years) excluded initial differential diagnoses of *i*. hamstring syndrome and *ii*. ischio-gluteal bursitis when pain persisted despite intervention. After further investigation, PFM hypertonic disorder (non-relaxing PFMs) was diagnosed, and upon revised intervention of soft tissue mobilization to address the increased PFM tone on the left, the pain resolved resulting in return to distance running (9). This case study indicates that unilateral tightness of the PFMs could impact on both pain and function.

Certain pelvic disorders e.g. stress urinary incontinence and pelvic organ prolapse, are more prevalent during physical activity (85). Recent balance studies with load catching in standing found that incontinent women have higher PFM activation than continent controls (35,36). This challenges the clinical assumption that incontinence is associated with reduced PFM activity or weakness, and introduces the concept that the PFMs have balance and postural functions. Populations with strong PFMs also experience stress incontinence with strenuous physical activity, and as such strength of PFM contraction does not always correlate with continence state (86). The pathophysiology of injury and involuntary action is not yet well understood. Changes in lumbo-pelvic posture are found to affect both PFM contractility and vaginal pressures generated during static postures and dynamic activities (22).

Pelvic disorders are a global phenomenon. They are most prevalent in parous women (2); they occur naturally with aging (2); and are prevalent during standing, or with physical activity like high impact sport (85). Pelvic disorders are not exclusively female, with male and child populations also experiencing pelvic dysfunction. Pelvic disorders have symptoms associated with PFM dysfunction and are divided into five groups: lower urinary tract symptoms, bowel symptoms, sexual function, prolapse, and pain (7). A standardised terminology report (2005) includes sub-classifications for contracting / relaxing PFMs, and non-contracting / non–relaxing PFMs; and assesses both voluntary and involuntary activity. This classification accounts for involuntary PFM activity and recognizes the role of relaxation or lengthening as part of normal function.

The aim of the study was to describe the EMG activity of the PFMs in healthy nulliparous female adults during the various weightbearing phases of the gait cycle. The primary objectives included reporting on subject characteristics; describing a Base Level of PFM EMG activity in standing; describing PFM EMG activity during gait; and establishing the support status with respect to time and its impact on PFM EMG activity. Secondary objectives were describing PFM EMG activity at rest (baseline), during MVC and sub-max in standing to establish a Base Level whilst weightbearing.

3.2. Methods

3.2.1. Study design and research setting

This study was designed as a descriptive observational study, and conducted at the 3D Motion Analysis Laboratory, Tygerberg Campus, Stellenbosch University in June and August 2016. It focuses on the description of PFM EMG activity in relation to the various weightbearing phases of the gait cycle. Stellenbosch University Health Research Ethics Committee approved the study (# IRB0005239; S15/08/170). All subjects signed written consent on the day of testing, prior to set-up; Addendum G, and completed feedback after the test; Addendum J.

3.2.2. Recruitment

Recruitment initially consisted of lectures to selected allied health sciences students (undergraduate physiotherapy and postgraduate midwifery) at Stellenbosch University. They were asked to volunteer if they were *i*. female; *ii*. pelvically healthy; *iii*. nulliparous; and *iv*. adults aged 20 years and older. A second round of recruitment involved poster placement at exercise institutions (the Sports Science Institute of South Africa, and private Pilates & Yoga studios). Final recruitment consisted of an email request to relevant physiotherapy groups in the greater Cape Town area (Women's Health

Physiotherapy Group, and the Western Cape branch of the South African Society of Physiotherapy). Volunteers were excluded if they *a*. had pelvic dysfunction established via The Australian Pelvic Floor Questionnaire, Addendum H (bladder, bowel and sexual function); *b*. had current low back or pelvic pain; *c*. had been pregnant; *d*. were *virga intacta*; *e*. menstruating on the day; or *f*. had a known neurological condition that might compromise muscle function. Figure 3.1 is a flow-chart of the recruitment process. Appointments were scheduled at the 3D Motion Analysis Laboratory, Tygerberg Campus, Stellenbosch University. Volunteers were asked to wear loose fitting clothing to the study.

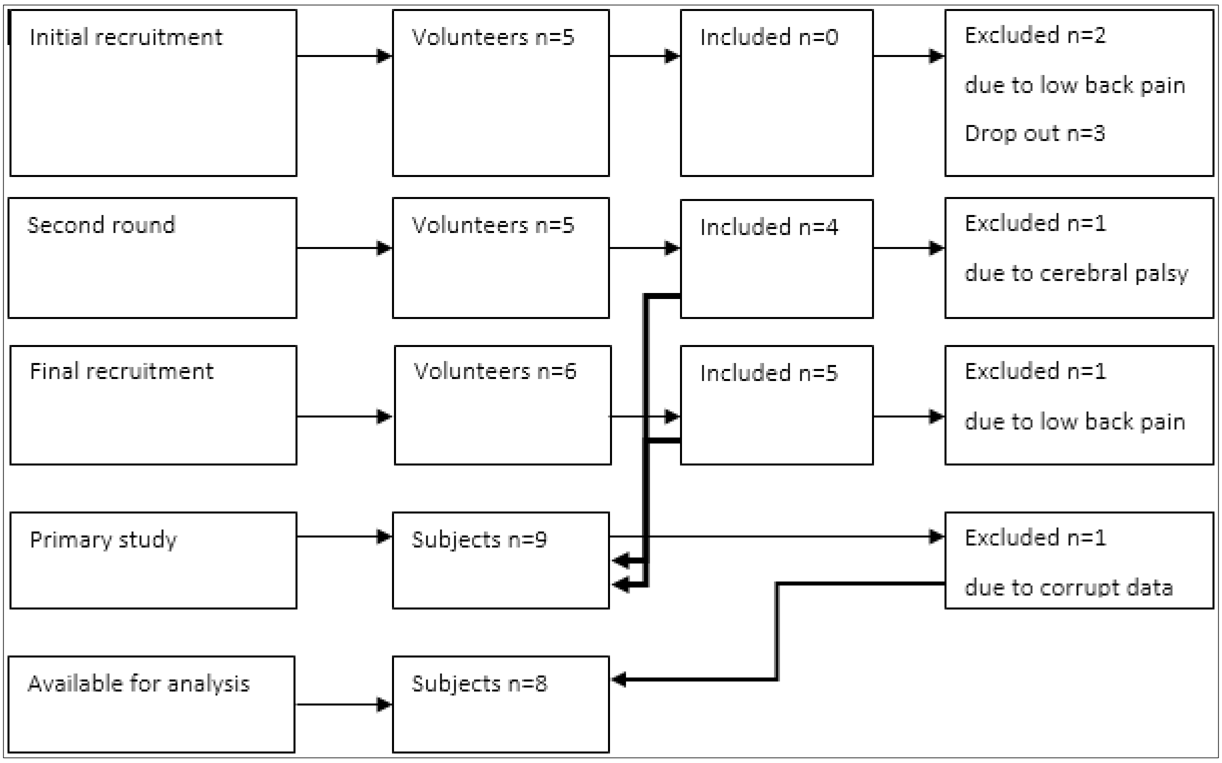

Figure 3-1 Flowchart of recruitment and subject selection

3.2.3. Instrumentation

Several internal vaginal surface electrodes have been shown to be reliable and valid. For the purposes of this study the Periform® electrode (Neen, UK) was selected due to its dimensions minimizing movement in the vagina (87) (88) (89), and availability in South Africa; figure 3.2. The electrode is used routinely in clinical practice and has had reliability testing during running (17). The PFM EMG was captured via wireless (RF) communication and synchronised with the gait data with respect to time.

Figure 3-2 Periform® Electrode

Three-dimensional motion analysis used an 8-camera system (VICON). This system incorporates infra-red sensitive solid-state cameras for locating and tracking fixed reflective markers through space. The four markers were passive-reflective spheres (diameter 14mm) and were affixed with double-sided tape to the heel (mid-point of the calcaneus) and toe (head of the second metatarsal) bilaterally; figure 3.3. VICON was selected due to availability, and the proven reliability and validity of the data capture system (90-92).

The self-administered Australian Pelvic Floor Questionnaire (English) was selected to assess pelvic dysfunction as per eligibility criteria. It assesses pelvic floor function in a reproducible and valid fashion and due to its responsiveness has been found appropriate for routine clinical assessment and outcome based research (93). It is scored out of a total of 116, with bladder function rated out of 45, bowel out of 34, prolapse out of 15, and sexual function out of 22; Addenda C and D. Questions score no dysfunction as 0, with increasing dysfunction scoring up to a maximum of 3; therefore, low scores indicate little dysfunction and higher scores indicate increasing pelvic dysfunction.

3.2.4. Procedures

Subjects attended one session. Either a gait lab engineer or technician was available onsite to assist with equipment calibration for most testing. Inclusion eligibility was confirmed by completing the self-administered Australian Pelvic Floor Questionnaire; Addendum H. Subjects were asked to empty the bladder, then remove shoes to be measured and weighed (BMI). Thereafter, they underwent standardized set-up with placement of heel and toe markers for 3D motion analysis data capture; figure 3.3. A wireless EMG (Noraxon) data capture unit was attached below the waist (right ASIS[6]) with double-sided tape (2cm²); figure 3.4. They were instructed in the self-insertion of the internal vaginal electrode, which they did in a private area. On successful insertion of the electrode, the primary investigator (PI) attached the connectors of the electrode to the previously affixed wireless unit.

Figure 3-3 Heel and toe reflective sphere markers

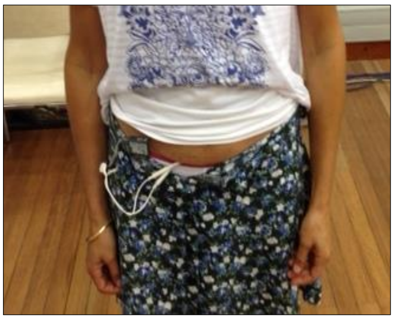

Figure 3-4 Wireless data capture unit (Noraxon)

There was no commonly accepted method of capturing, analysing and reporting on Base Level. In the studies reporting on PFM EMG during running; Luginbuehl et al measured PFM EMG twice for 30 seconds at rest and twice for 5 seconds during MVC in both standing and supine whilst establishing intra-session test–retest reliability of PFM EMG during running (17). When reporting on PFM EMG during different running speeds they measured PFM EMG twice for 15 seconds at rest and twice for 5 seconds during MVC with a 15 second break between each contraction in standing only (18). Stafford et al did not establish a Base Level per se. They presented data of PFM EMG with movement relative to at rest, including single leg stepping, arm movements and loading catching (14). We chose to include a submaximal contraction, as it has more activity than at rest and less than during MVC in standing.

Pelvic floor muscle EMG activity was investigated to establish a Base Level during weightbearing. This comprised three ‘states’ of voluntary PFM activity in standing – at rest (baseline), with maximum voluntary contractions (MVC), and during a sub-maximal contraction (sub-max). All contractions were performed with a 10 second rest interval. They began with 30 seconds at rest (baseline); then performed three repetitions of MVCs for 5 seconds each, and finished with one sub-max contraction for 20 seconds; table 3.1 for verbal instructions.

On completing the Base Level, subjects were instructed to walk six times the length of the 3D motion analysis data capture area (one length approx. 6m), at a brisk but comfortable self-selected pace. Data from each of the six ‘walks’ was captured separately, and end (or turning) steps were excluded from the final analysis; table 3.1.

[6] ASIS – anterior superior iliac spine

Table 3-1 Verbal instructions given for PFM activity during Base Level and gait

PFM activity	Verbal Instruction
At rest	"Relax, let go, focus on your breathing"
Maximum Voluntary Contraction	"Stop a wind, hold a wee, keep squeezing hard…" (after 5 seconds) "… and let go."
Sub-maximal contraction	"Squeeze gently & easily; just a little, keep holding it for 20 seconds, and breathe, don't let go…" (after 20 seconds) "… and let go."
Gait	"Do not squeeze your pelvic floor. Ignore the electrode. Walk freely and briskly from one side to the other, then turn, stop and repeat."

Gait has three main descriptors: *time* as a percentage; *phase of gait* relative to the position of the lower limbs (stance or swing phase, and multiple sub-classifications) and *weightbearing status.*

Weightbearing status describes standing on one or both lower limbs, known as single support and double support respectively. The gait cycle comprises of one full stride revolution through a lower limb, including both stance and swing phases.

In figure 3.5, the cycle starts with right heel strike at time zero, or 0% of the cycle. The first double support loads onto the right for 0-12% of the cycle. This is followed by single support on the right from 12-50%. The second double support loads onto the left from 50-62%, and the gait cycle is completed by single support on the left from 62-100%.

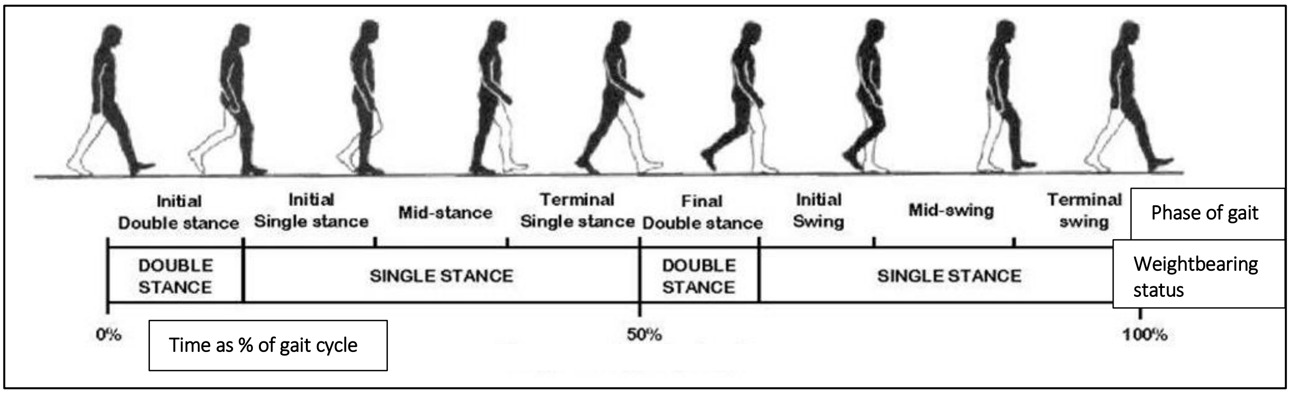

Figure 3-5 Gait cycle relative to right lower limb; time (%), weightbearing status, phase of gait [7]

3.2.5. Data reduction

Electromyography and 3D motion analysis data were bandpass filtered between 20 and 500Hz, with an RMS smoothing and a window of 300ms. Base Level testing in standing was selected instead of the usual testing in lying as it is more functionally comparable with gait (94). Given impact is less during walking than running, we selected 100% MVC as equivalent to the maximum PFM EMG activity achieved in standing. This differs from the running studies where 100%MVC was taken as the average of the two peak amplitudes (17,18). The three MVCs were averaged, and presented as the mean of all three contractions. Onsets and offsets were calculated on smoothed data. For the two active phases of Base Level activity in standing (MVC and sub-max), PFM activation onset was detected as the start of a 50ms window during which the average PFM activity was more than 2 SD above the average signal for the rest period, after approx. 10 seconds of rest. Each MVC mean was calculated over 5 seconds (11,22,95). In cases where false or missed onset detections occurred, data was checked by visual inspection. The different time and activity variables are shown in table 3.2.

[7] http://what-when-how.com/pattern-recognition-and-image-analysis/human-recognition-based-on-gait-poses-pattern-recognition-and-image-analysis

Table 3-2 Description of time & activity variables derived from motion analysis and PFM EMG [8]

Variable (unit)	Description	To identify	Time % of gait cycle	Gait graphs graphic representation
$T0^L$ (ms)	Heel strike left	Double support onto left	0%	
TX^R (ms)	Toe off right	Single support on left	± 12%	dotted vertical line
$T0^R$ (ms)	Heel strike right	Double support onto right	± 50%	solid vertical line
TX^L (ms)	Toe off left	Single support right	± 62%	dotted vertical line
EMG min (%MVC)	Min EMG activity	Periodic characteristics		lower wave margin
EMG max (%MVC)	Max EMG activity	Periodic characteristics		upper wave margin
EMG min-max (%MVC)	Range EMG activity	Range and deviation		thickness of wave

3.2.6. Statistical analysis

Descriptive stats were performed for each variable. All normally distributed data was expressed as means and standard deviations. Non-normally distributed data was expressed as medians and intra-quartile ranges. Data was graphed over time. Although not using tests of association, subgroup analysis was conducted to explore associations over time between predictors of gait; the phase of gait and support status. Due to the small sample size, inferential statistics were not deemed appropriate. No power calculation was performed. This study used Excel, and conducted a data analysis of descriptive statistics. Confidence level was set at 95%.

3.3. Results

3.3.1. Subject characteristics

There were eight subjects available for data analysis; table 3.3. All subjects completed feedback in the form of Visual Analogue Scales, with no complaints from seven subjects across six categories (electrode insertion, electrode removal, pain, discomfort, burning, other). One subject rated electrode insertion at 1/10, and another subject rated electrode insertion and removal at 3/10, pain at 1/10, and discomfort at 4/10. She indicated she did not require follow up. Subject characteristics including age, BMI, PFM EMG during Base Level and gait are presented by subject in table 3.4. Base Level is presented in term of absolute (uV) and normalised (%MVC) values, and gait is presented as %MVC with respect to weightbearing status. There was one unit of missing data from the Australian Pelvic Floor Questionnaire*. All subjects scored 14 and less out of a possible 116; indicating minimal pelvic dysfunction; Addendum J. Language data was not gathered.

Table 3-3 Subject demographics

Parameter	Mean ± SD
Age (years)	33.5 ± 8.52
Weight (kg)	67.56 ± 14.60
Height (cm)	167.94 ± 6.63
BMI (kg/m^2)	23.98 ± 5.06
The Australian Pelvic Floor Questionnaire Score (116)	7.88 * ± 6.15
History of low back or pelvic pain – n (%)	2 (25%)
Lower limb presentations – n (%)	3 (37,5%)

[8] Analysis conducted on smoothed data

Table 3-4 Subject characteristics; PFM EMG during Base Level (uV, %MVC) & gait (%MVC)

Subject	Characteristic					Base Level						Gait trials			
						Absolute (uV)			Normalised (%MVC)			Normalized (%MVC)			
												Double Support		Single Support	
	Age	BMI	Questionnaire Score	Low back or pelvic pain	Lower limb presentation	Baseline	MVC	Sub-max	Baseline	MVC[1]	Sub-max	Loading onto left	Loading onto right	Left	Right
1	29	22,3	14	Nil	Nil	17 ± 2	54 ± 13	28 ± 5	20 ± 3	67 ± 16	35 ± 7	43 ± 7	40 ± 8	42 ± 7	40 ± 7
2	49	33.8	14	Nil	Left hip pain with exercise	10 ± 1	33 ± 9	14 ± 2	17 ± 3	57 ± 15	24 ± 4	32 ± 6	26 ± 3	31 ± 5	27 ± 5
3	40	17.3	0	History	Left ITB pain with exercise	9 ± 1	71 ± 14	27 ± 4	10 ± 1	75 ± 14	29 ± 5	23 ± 2	23 ± 2	23 ± 2	24 ± 2
4	27	28.4	3	Nil	Nil	22 ± 2	62 ± 18	28 ± 3	21 ± 2	60 ± 17	27 ± 3	34 ± 6	31 ± 6	34 ± 8	33 ± 8
5	25	22.3	4	Nil	Nil	25 ± 4	46 ± 10	31 ± 4	36 ± 6	67 ± 15	45 ± 6	83 ± 15	67 ± 10	74 ± 13	78 ± 23
6	36	24.6	12	Nil	Leg length discrepancy	37 ± 5	78 ± 16	59 ± 7	30 ± 4	63 ± 13	47 ± 6	42 ± 5	46 ± 8	43 ± 8	45 ± 7
7	37	20.8	2	Nil	Nil	12 ± 1	108 ± 24	91 ± 12	8 ± 1	72 ± 16	61 ± 8	30 ± 8	29 ± 8	29 ± 8	34 ± 9
9	25	22.3	14	History	nil	11 ± 2	40 ± 5	20 ± 3	20 ± 3	71 ± 8	35 ± 5	52 ± 8	53 ± 7	52 ± 8	53 ± 10

[1] As maximum PFM EMG achieved during the 3 MCVs equated to 100%MVC, the average across the 3 MVCs was less than 100%

3.3.2. Base level PFM EMG

Base Level was captured in uV, and converted to %MVC; where the absolute maximum uV PFM EMG achieved during the 3 MVCs was set to equal 100% MVC for each subject. See table 3.3 for absolute values and %MVC conversion per subject. Base Level provided data regarding voluntary PFM EMG activity when weightbearing bilaterally through both lower limbs simultaneously. It was comprised of three established states of voluntary PFM activity; at rest in standing (baseline), maximum voluntary contraction (MVC) and submaximal contraction (submax).

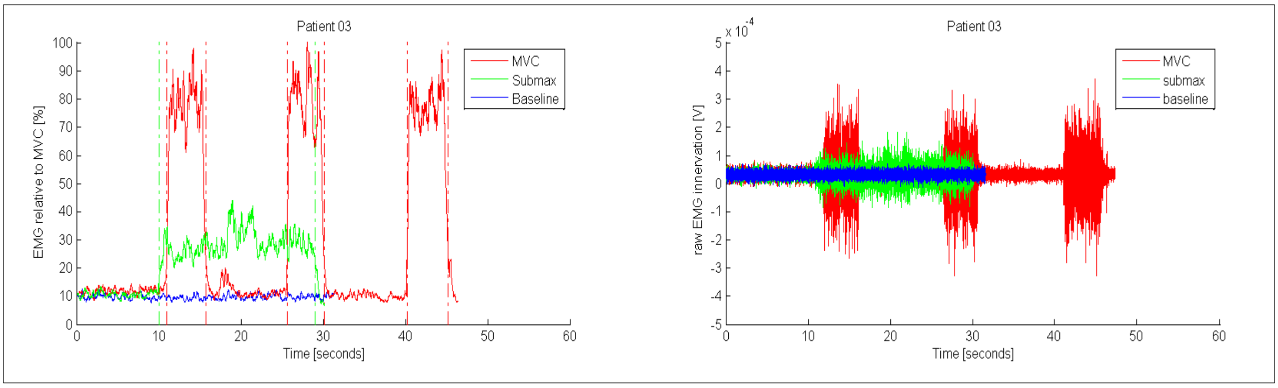

Figure 3-6 Example of Base Level PFM EMG in standing; raw (left) and smoothed (right)

3.3.2.1. Baseline

Baseline (at rest) was the lowest of all three voluntary PFM activity states in standing. It ranged from 9 – 37 uV; and 8% - 36% when normalised as %MVC. All subjects had low deviation at rest in standing.

3.3.2.2. Maximum Voluntary Contraction

Maximum voluntary contraction was the highest and most erratic of the three states. It ranged from 33 - 108 uV; or 57% - 75% MVC when normalised, where the maximum uV achieved equated to 100%MVC. Subject 09 was the only individual to display relatively little deviation between all 3 MVCs.

3.3.2.3. Sub-maximal contraction

Sub-maximal contraction was higher than baseline and lower than MVC in standing. It ranged from 14 – 91 uV; or 24 – 61 %MVC. There was less deviation than during MVC, but more than during baseline. Subject 07 used a high %MVC during sub-max contraction.

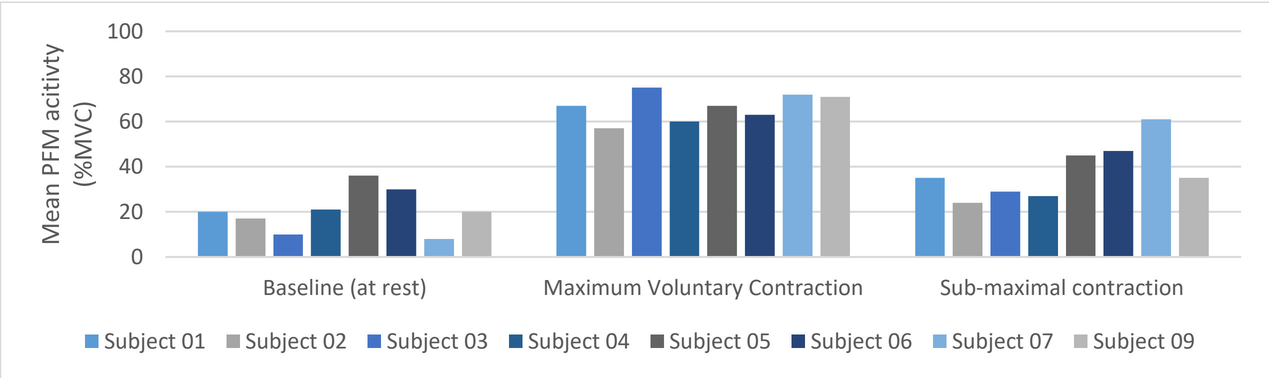

Figure 3-7 Means of PFM EMG as a %MVC during Base Level

3.3.3. PGM EMG during gait

The gait cycle refers to one complete stride, consisting of two consecutive alternate steps. It can begin anywhere in the cycle, but is considered complete when the forward foot returns to the weightbearing activity it was doing at time zero or 0% of the cycle e.g. heel strike or toe of. We selected heel strike as time zero, and results are presented for both the left (red) and right (green) lower limbs; figure 3.8.

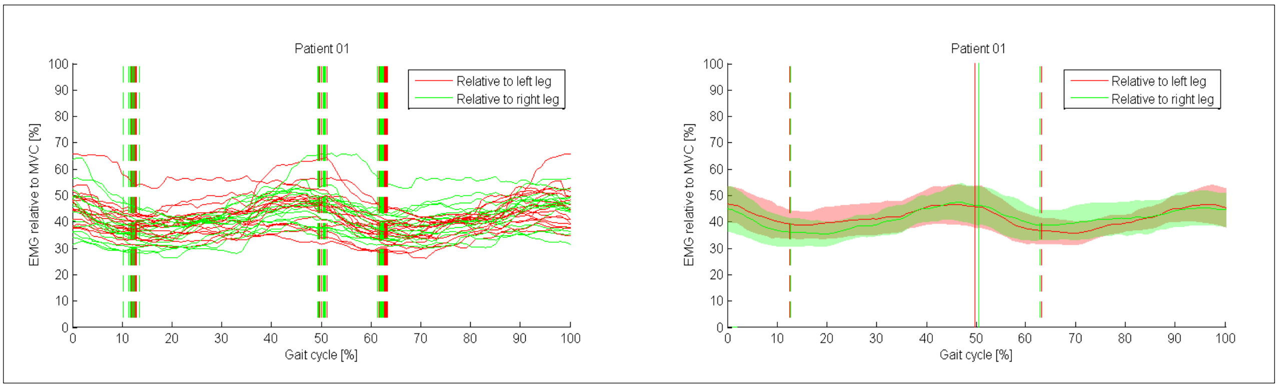

Figure 3-8 Example of PFM EMG during gait [1], raw (left) and smoothed (right)

During gait, involuntary PFM activity shows low intra-subject variation with individuals using a similar %MVC throughout, whilst inter-subject variation is high with individuals using varying amounts of involuntary PFM activity as a %MVC during gait; figure 3.9. Subject 05 uses high levels of %MVC during gait – from 65%MVC – 80%MVC, whereas subject 03 uses as little as 20%MVC PFM activity throughout the gait cycle.

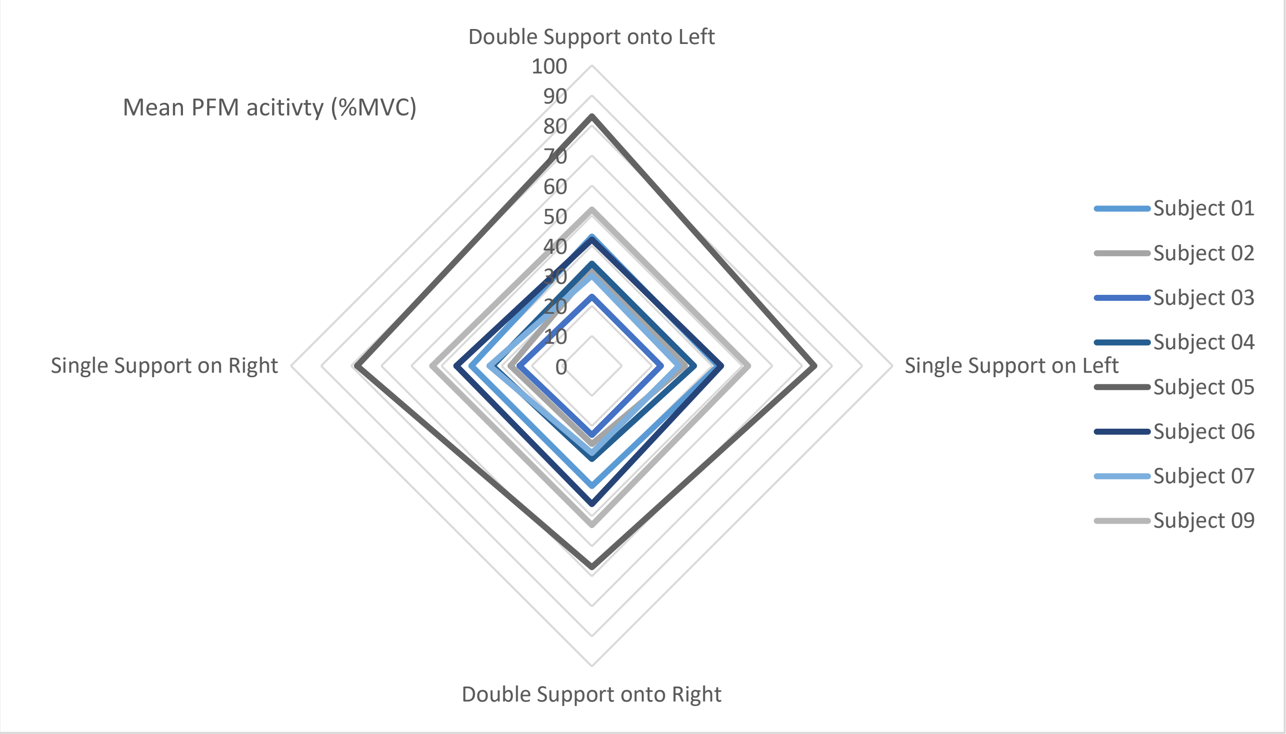

Figure 3-9 Means of PFM EMG as a %MVC during gait by weightbearing status

[1] Legend: **Lower limb –** RED is relative to the left lower limb, GREEN is relative to the right lower limb. **Timing** – the dotted vertical lines are the *opposite side initial foot off* or toe off (indicating end of first double support phase) and *same side initial foot off* or toe off (indicating the end of the second double support). The solid vertical line is the *opposite side initial foot contact* or heel strike (indicating the start of the second double support phase). **Range** is evident in the height as a %MVC of the wave. **Amplitude** - the thickness of the wave is indicative of the degree of variability. **Wave pattern** – the shape of the wave.

As PFM activity during gait is non-normally distributed, the average of intra-quartile ranges for each support phase are seen to have low variability (approx. 10%MVC and below), except for subjects 05, 07 and 09; figure 3.10. Subject 05 has an average deviation equivalent to 34% MVC during single support on the right. This indicates little difference within subjects, which may indicate subject specific PFM activation patterns during gait.

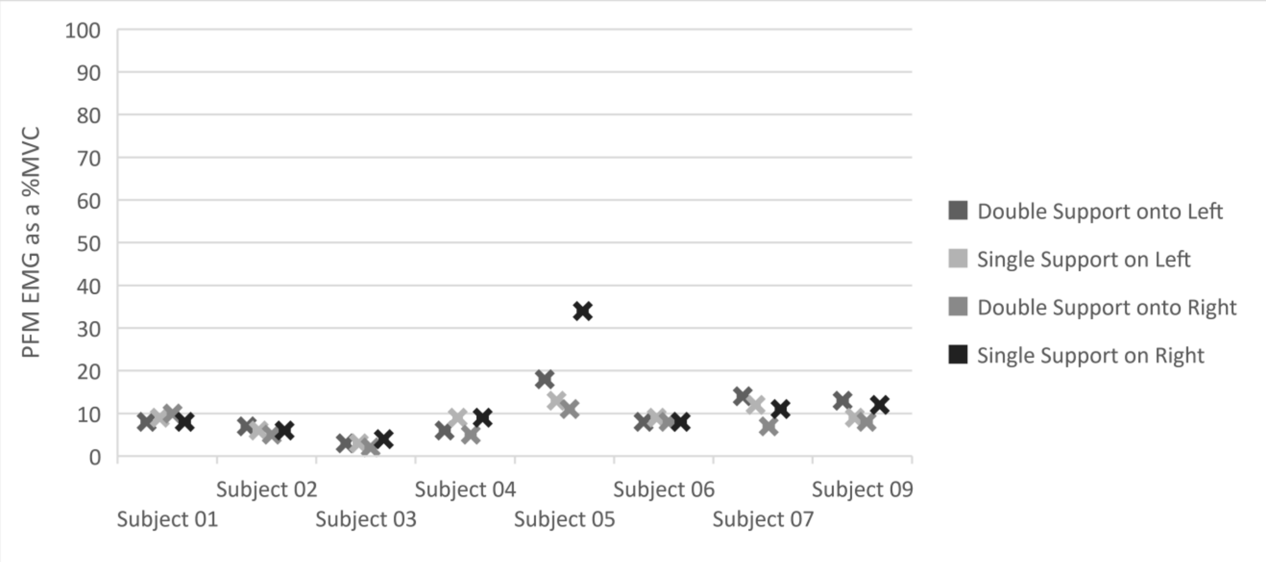

Figure 3-10 Intra-quartile ranges of PFM EMG as a %MVC during gait by subject

A characteristic wave pattern emerges, of decreasing PFM activity during double support, and variable strategies during single support; figure 3.11. PFM EMG activity initially rises during single support, and either keeps doing so, or reaches a peak and then begins to hall again, into double support.

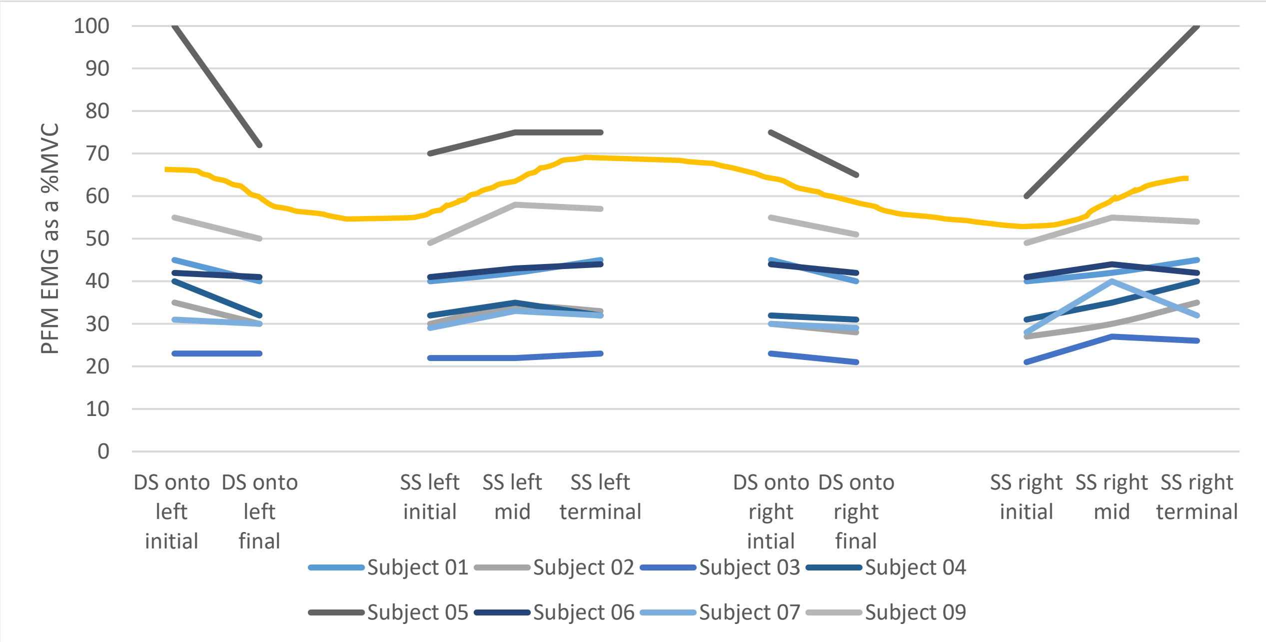

Figure 3-11 Wave pattern of PFM EMG activity during the weightbearing phases of gait

Descriptive stats for PFM EMG during gait are found in table 3.5.

Table 3-5 Descriptive stats (Mean ± SD) for PFM EMG during Base Level and gait (%MVC)

Activity	Variable	Units	Descriptor	PFM EMG Mean ± SD
Base Level	Baseline	%MVC	At rest in standing	20.25 ± 9.33
	MVC	%MVC	MVC in standing	66.5 ± 12.39
	Sub-max	%MVC	Sub-max in standing	37.875 ± 6.19
Gait	$T0^L – TX^R$	%MVC	From heel strike left to toe off right Double Support onto left	42.375 ± 8.71
	$TX^R – T0^R$	%MVC	From toe off right to heel strike right Single Support on left	41 ± 16.18
	$T0^R – TX^L$	%MVC	From heel strike right to toe off left Double Support onto right	39.375 ± 15.20
	$TX^L – T0^L$	%MVC	From toe off left to heel strike left Single Support on right	41.75 ± 17.42

Pelvic floor muscle EMG during gait is discussed per subject. Subjects are first presented in terms of subject characteristics. They are further described in terms of:

i. Range (%MVC), which indicates the amount of involuntary PFM activity used during gait e.g. 20-30%MVC vs. 40-55%MVC

ii. Timing (dotted and solid vertical lines), spaces between the vertical lines indicate differences in timing between the end of first and second double support (dotted lines at approx. 12% and 62% of the gait cycle) and single support (solid line at approx. 50% of the cycle)

iii. Amplitude (thickness of the wave), indicating the amount of variability of involuntary PFM activity during gait

iv. Wave pattern (red and green waves) indicating degree of similarity in PFM activation relative to the left (red) and right (green) lower limbs

Common areas of overlap are khaki green and indicate the same PFM activation based on the phase of gait be it through the left or right lower limb.

Electromyography of the PFMs during gait was sensitive enough to identify individual variations in range, amplitude and wave pattern. Differences in timing were identified by 3D motion analysis.

Subject 01

Subject 01 was 29 years old, had a BMI of 22,4 kg/m^2, scored 14/116 on the Australian Pelvic Floor Questionnaire, and had no history of low back or pelvic pain. Her range of PFM EMG was approx.[2] 30% - 55% MVC. She was reasonably symmetrical in terms of timing, amplitude and wave pattern, with slightly more variability of PFM activity seen during early-to-mid single support on left; figure 3.12.

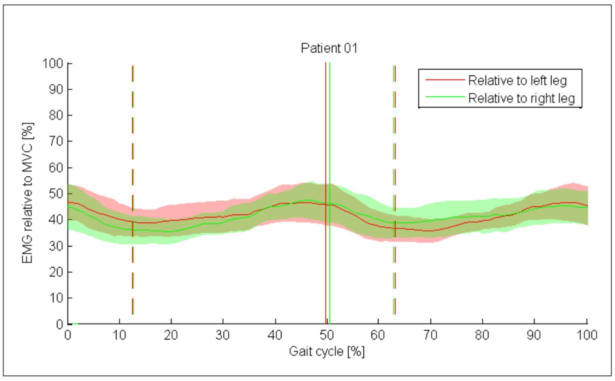

Figure 3-12 PFM EMG during the gait cycle; subject 01

Subject 02

Subject 02 was 49 years old, obese (BMI 33,8 kg/m^2), scored 14/116 on the questionnaire, had no previous low back or pelvic pain but complained of left hip pain during exercise with fatigue. She exhibited a range of approx. 20% - 40% MVC. She was not symmetrical, with greater PFM activity during double support onto left than loading onto the right. Activity peaked earlier during single support on left. She also had differences in timing, seen by the spacing between the dotted vertical lines; figure 3.13.

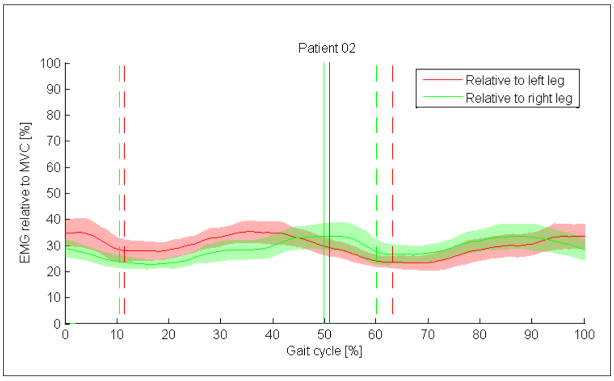

Figure 3-13 PFM EMG during the gait cycle; subject 02

Subject 03

Subject 03 was 40 years of age, and underweight with a BMI of 17,3 kg/m^2. She scored 0/116 on the questionnaire. She had a history of low back pain, and complained of left ITB pain with fatigue during strenuous exercise. She used as little as approx. 20% - 28% MVC with very little deviation. She exhibited differential PFM activity during middle single support, with more activity during single support on the right than on the left. She exhibited marked differences in timing as seen by the space between the vertical lines, both single support and double support; figure 3.14.

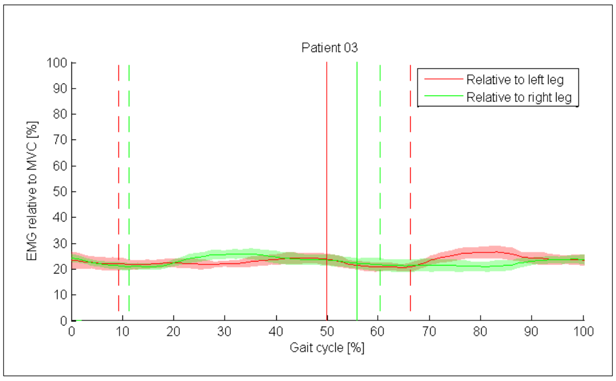

Figure 3-14 PFM EMG during the gait cycle; subject 03

Subject 04

Subject 04 was 27 years old, and overweight with a BMI of 28,4 kg/m^2. She scored 3/116, and had no history of note. She ranged between approx. 25% - 50% MVC, with greater variability when weightbearing on the right during single support. She also displayed timing differences; figure 3.15.

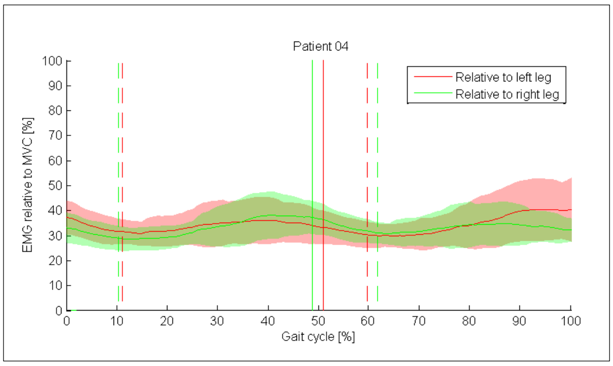

Figure 3-15 PFM EMG during the gait cycle; subject 04

[2] As a % of smoothed data. The raw data would yield a greater range due to outliers.

Subject 05

Subject 05 was 25 years old, within normal BMI range at 22,3 kg/m^2, scored 4/116 and had no pain complaints. Out of all the subjects, she presented with the greatest variability of involuntary PFM activity during gait, from 50% to greater than 100% MVC. She also had notable difference between left and right; during both double support and single support. During double support, she had greater activity when loading onto the left. She had similar PFM activity early-to-mid single support, but greater activity on the right than the left in mid-to-late single support. Her timing was symmetrical.

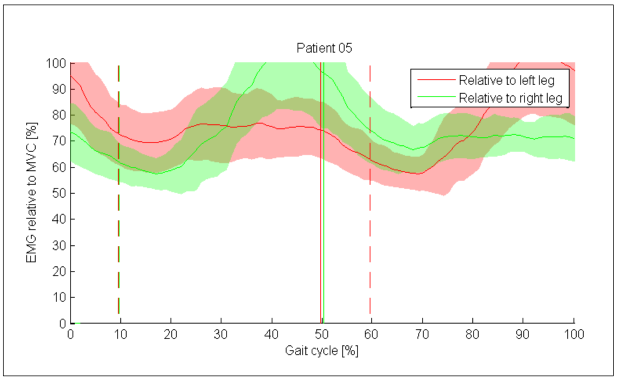

Figure 3-16 PFM EMG during the gait cycle; subject 05

Subject 06

Subject 06 was 36 years of age, had a BMI of 24,6 kg/m^2, scored 12/116, and had no history of pain. She did have a known leg length discrepancy secondary to *talipes*. She ranged between approx. 32% - 58% of MVC, and had difference in timing, and during both single support and double support. In double support, she used less PFM activity when loading onto the left, and in single support she had earlier onset activity when weightbearing on the right versus the left.

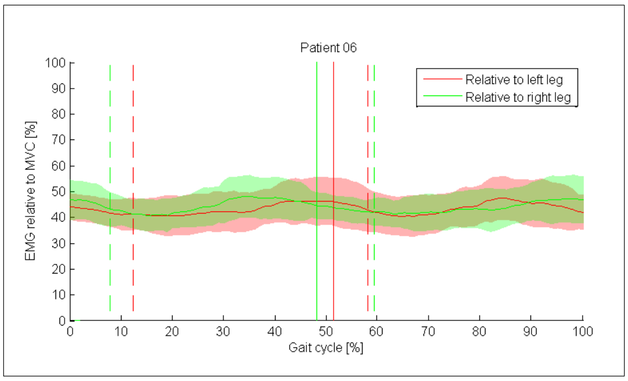

Figure 3-17 PFM EMG during the gait cycle; subject 06

Subject 07

Subject 07 was 37 years old, had a BMI of 20,8 kg/m^2, scored 2/116, and had no low back or pelvic pain. She ranged from approx. 20% - 45% MVC. She had similar PFM EMG during double support, but used more during early-mid-to-late single support on the right. Her timing was slightly asymmetrical.

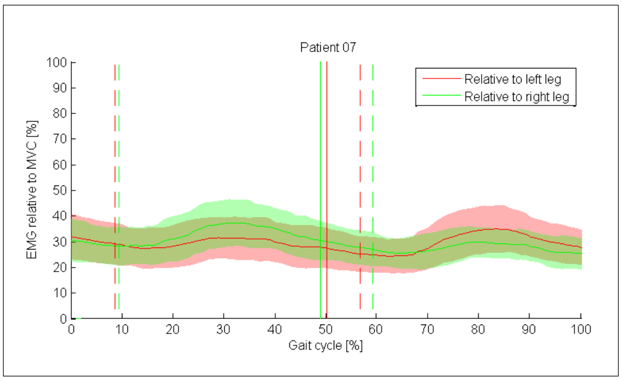

Figure 3-18 PFM EMG during the gait cycle; subject 07

Subject 09

Subject 09 was 25 years old; had a BMI of 22,3 kg/m^2, scored 14/116, and had a history of low back pain. She ranged from approx. 40% - 70% MVC during gait, and had more PFM activity during middle single support on the right. She had minor, and similar, timing differences

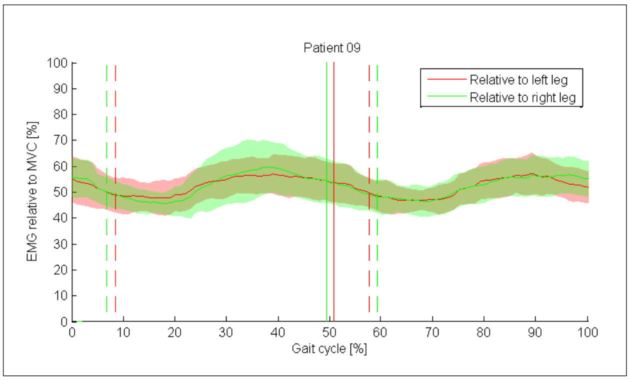

Figure 3-19 PFM EMG during the gait cycle; subject 09

3.4. Discussion

The aim of this study was to describe the EMG activity of the PFMs during the various weightbearing phases of the gait cycle. To the best of our knowledge, it is the first to do so. Whilst no specific trends exist, patterns of regular increasing and decreasing PFM activity emerge.

A systematic review into PFM displacement during voluntary and involuntary activation in continent and incontinent women (86) reported that PFM displacement is influenced by multiple factors, including the task, the diagnostic instrument, the test position, continence status, age, muscle condition and fascial structures. They went on to acknowledge that whilst their findings "summarise the present knowledge of PFM displacement, we still lack deeper comprehension of the stress urinary incontinence patho-mechanism of involuntary, reflexive activation during functional activities". Our study has sought to identify the degree to which involuntary reflexive activity occurs in the PFMs during normal human gait. In so doing, it has identified periodic characteristics of PFM activity.

There is evidence in the literature that suggests differential PFM function between left and right side of the PFMs (22,78,89). Despite poor sample size, our study has identified differential PFM EMG activity, based on the lower limbs, with respect to weightbearing.

3.4.1. EMG variables

PFM EMG via surface vaginal electrode has been found to be reliable (89) and retest-able (94). The presence of a vaginal probe does not alter PFM activity (88) and has a strong correlation with digital palpation as a means of measuring contraction of the PFMs (96).

Only two studies to date have reported on data of PFM EMG during gait; in both cases during running (17,18). Luginbuehl et al (17) investigated the intra-session test–retest reliability of PFM EMG during running with a Periform® electrode, and found that relevant PFM EMG variables during running (e.g., pre-activation, minimal and maximal activity) could be identified and showed good reliability. They reported that the highest reliability indexes were found for all EMG derived variables with ICCs superior to 0.750 and ranging between 0.906 and 0.942. They found less reliability with time variables; with ICCs ranging from 0.113 to 0.731. Running differs from walking in that there is significantly greater impact at heel strike. It also has no double support phases. Weightbearing never occurs through both lower limbs at the same time during running; weight transfer from one side to the other happens in the air. Our study identified that despite the variations, PFM EMG activity during gait can be described as decreasing in double support, irrespective of limb loading, and increasing during single support. The variations in single support are both between subjects and between limbs within subjects, figure 3.19. Visually, PFM EMG activity during the various weightbearing phases of the gait cycle can be described as a reasonably symmetrical sinusoidal wave of varying height. Where asymmetries exist, they can be attributed to range, amplitude, wave pattern and timing. PFM EMG activity is higher during gait values than voluntary sub-max PFM contractions in standing, with greater deviation.

3.4.1.1. Range

Subjects use varying percentages of MVC (established in standing) during gait. In the first study of its kind, exploring PFM EMG during running and testing reliability thereof, Luginbuehl et al found a mean baseline (at rest) in standing of 29.6% MVC. They reported that during running PFM EMG activity varied based on speed, with slower running speeds of 7 km/h and 9 km/h being similar and lying between 67.6% MVC and 88.4% MVC. Only faster running at 11km/h led to higher PFM values rising to 106.1% MVC (18). Our sample had a lower mean baseline of 20.25% MVC. During gait, we found mean EMG min for three of the weightbearing phases (single support on left, double support onto right, single support on right) to be as low as 24%, with double support onto left higher at 33%. Mean EMG max ranged from 51% MVC to 59% MVC during gait. We did not gather data on dominance (upper and/or lower limb). Differences in resting PFM activity could be attributed to the differences in populations sampled; their population was younger 24.9 years ±3.3 and had a BMI of 21.6 kg/m^2 ±2.7; vs. our population at 33.5 years ±8.52 and 23.98 kg/m^2 ±5.06.

3.4.1.2. Amplitude

The variation of PFM activity is evident in the thickness of the wave. Some subjects show very little deviation in amplitude indicating very similar levels of PFM activity; whilst others have thicker waves indicating greater variability in involuntary PFM activity during gait. Luginbuehl at al reported that high reliability indexes were found for all EMG-amplitude-derived variables during running (17). We found a large variation of amplitude across the 8 subjects in our sample. Given that this was in a healthy nulliparous population, there is likely to be a wide range of variation in clinically relevant populations.

3.4.1.3. Wave pattern

Gait is a series of recurring movements, and is considered a bilateral whole body movement. Patterns are evident; and differ if the strategy changes e.g. between forwards and backwards locomotion (5) or when walking with the Masai Barefoot Technique (97). Whilst predominantly sinusoidal in nature, differences are evident between left and right. These differences should not be confused with activity of the left or right PFMs, but rather the activity in the PFMs when weightbearing on left or right. Most variation is seen during single support, specifically mid to terminal single support. The greater variation seen during single support implies that the PFMs are more active during standing on one leg, than they are when transferring weight from one leg to another during double stance, where less variation of PFM activity is evident. Of note: PFM activity decreases during double support, but exhibits greater variability (starting low, increasing to a maximum and potentially beginning to drop again) during single stance.

3.4.2. Time variables

Time variables show large variation. This is evident in the range seen in heel strike ($T0^L$ and $T0^R$) and toe off (TX^L and TX^R) variables – indicated by the solid and dotted vertical red and green lines respectively. Even is a seemingly healthy population, a degree of asymmetry is evident. Luginbuehl et al reported time variables showed large ranges and therefore low reliability in a study during running with PFM EMG. They used accelerometers on the lateral malleolus of the right leg to identify the time point of heel strike (T0), on the sacrum, and on the external part of the vaginal probe to identify the vertical impacts (17). Data from one lower limb (the right) was presented. We wanted to describe the impact of weightbearing, and hence weight transfer through the pelvis from left to right and vice versa during double support. The variation in timing indicates different weightbearing strategies during both single and double support in healthy nulliparous female subjects

3.4.3. Extrinsic and intrinsic pressures

Shoes, especially high heels, have been shown to have an impact on PFM activity (98). Ankle position is also found to effect PFM activity (19). In contrast to other studies reporting on PFM activity during gait, our subjects were barefoot. This might have impacted the data if subjects were unaccustomed to walking without shoes by altering PFM activity at impact, and during weight transfer and weightbearing (97). No data was gathered on fore-foot vs. hind-foot gait patterns.

Subjects were instructed to empty the bladder as part of standardised set-up. The bladder volume prior to testing was not confirmed with a bladder scanner, or by catheterisation. Bladder volume has a known impact on PFM activity with tonic activity significantly higher in the full and uncomfortably full bladder states compared to when the bladder was empty ($p < 0.005$); however phasic maximum voluntary contractions were unaffected by the state of bladder fullness ($p = 0.713$) (99). If subjects in our study did not empty the bladder effectively, it may have affected our data, by altering PFM activity. Clinically, patients with altered PFM activity, often have co-morbid presentations of incontinence and pain (100).

3.4.4. Strengths and limitations

Technology is such that internal vaginal electrodes capable of being used in upright dynamic activities do not differentiate between left and right. The Multiple Array Probe Leiden (MAPLe) (78) has 24 electrodes and can differentiate between left and right PFMs, but is not feasible for use during dynamic weightbearing activities due to its shape – it won't be retained in the body upright against gravity. Based on the hypothesis that weightbearing affects PFM activity; by measuring the non-weightbearing hemi-pelvis and including its activity with the weightbearing hemi-pelvis, we mask any actual differences between left and right sides of the PFMs. Furthermore, as EMG measures activity, it doesn't differentiate between concentric (shortening, whilst active) and eccentric (lengthening, whilst active).

The sample was small. The age and BMI range was wide. They could have influenced the variation seen in our data. There were three subjects with known lower limb discrepancies, who met the inclusion criteria. A larger sample may have allowed for sub-group analysis of subjects with known lower limb presentations.

Due to funding limitations, motion analysis was limited to heel and toe markers. Additional motion analysis markers would give more insight into the biomechanics of the lumbo-pelvis and lower limb during gait to better inform of load transfer. Adequate funding would allow for multiple markers, with greater analysis of pelvic movement including pelvic translation and rotation during single and double support. Combined with a greater range of functional weightbearing activities e.g. climbing and descending stairs, hopping and jumping, more definable patterns of PFM activity may emerge.

Test procedure could have further influenced for weightbearing comparisons by including lying as an additional position in which to gather Base Level data, and adding in stairs. Hopping (on one lower limb) and jumping (on two limbs) might have yielded differences in PFM activity between left and right. Stair climbing, both up and down, could also have provide more insight into the actual effect of weightbearing through the lower limb. Running may have offered more obvious profound results by stressing the locomotor function of the pelvis, but it was decided against, due to the increase in variables, and no weight transfer through the pelvis, as happens during double support. Testing could have been conducted on a treadmill, to allow subjects to enter a constant state, after a defined warm up period.

Due to the limitations in methodology and testing, and the inherent technological shortcomings; this study provides the first general insights into PFM activity during gait. It does not describe activity of the left and right PFMs during gait, but rather an overall pattern of PFM activity, with respect to weight transfer (as found during double support) and weightbearing (experiences during both double and single support) as found during normal human gait.

3.4.5. Recommendations for future research

Future studies should consider sample size. The effect of age, BMI, parity and pelvic health status (known pelvic dysfunction) on PFM activity during gait should be established; as should potentially differential function between females and males.

3.4.6. Conclusion

The PFMs display involuntary activity on EMG during gait in healthy nulliparous female adults. Subjects use varying levels of PFM activity during gait and differ widely from each other; however, they show relatively little variation within themselves, with clear wave patterns emerging.

Involuntary activity of the PFMs during gait is evident. It appears to approximate a voluntary submaximal contraction in standing, although it shows greater deviation. The causes and impacts of differences seen in range, amplitude, wave pattern and timing are yet to be determined.

Chapter Four
Discussion

4.1. Contribution to the knowledge

Measurements of the PFMs during gait are in their infancy. Recent research contributions can be attributed to technological advances, specifically wireless communication (15,16,18,58) which has allowed for greater subject freedom from imaging hardware, both in and out of the laboratory. Weightbearing activities, such as standing, walking, lifting and carrying are acknowledged as being clinically significant in many populations, and the research is increasingly investigating PFM function during dynamic activities. This is in preference to relying on data captured in lying, or during an active straight leg raise to mimic weightbearing through the pelvis, and a Valsalva manoeuvre to mimic increases in intra-abdominal pressure.

The vagina has long been viewed as the most convenient of the three pelvic lumens within which to examine intra-pelvic function. Vaginal probes are used by the three main technological modalities – EMG, pressure, ultrasound – reporting on data of the PFMs captured during gait or weightbearing. All commercially available intravaginal probes have deficiencies in their design. Considerations when selecting an EMG probe include probe geometry (dimension and shape); and electrode size, location, and configuration (87). The same can be said for pressure devices; which differ in size, density, and area of pressure transmission. Ultrasound probes were used in standing, but not with dynamic movement due to motion artefact.

Electromyography is not without its faults; inter-session reliability, cross talk, and motion artefact are known shortcomings. Auchincloss et al reported that EMG of the PFMs via internal vaginal probe with surface electrodes has good within-day reliability, although poor reliability when monitoring PFM activity over time. They state that two commercially available internal vaginal probes (the Femscan© and the Periform®) are appropriate for use in studying PFM activation within an experimental session, and should produce data with adequate reliability to see significant results, between testing trials. They go on to caution that the stability of recordings over time has not been established; mentioning a 3-5min period between trials (89). The Periform®, although limited due to electrode configuration, has other advantages. In a recent 'State of the Art Review: Intravaginal Probes for Recording Electromyography from the Pelvic Floor Muscles' probes with longitudinal electrodes (on either side as opposed to around the circumference of the probe) were less likely to record crosstalk as the electrodes are positioned only at the lateral vaginal walls. Its pear-shaped dimensions are preferable to cylindrical probes for minimising motion artefact. It was also one of three probes to have reliability data published in peer-reviewed journals (87).

However, the lack of specificity (being able to differentiate left from right, superficial from deep, and front from back) is a major limitation. Electromyography data presented during gait is a total EMG reading from all PFMs combined, and as such any high activity in one area is evened out by low activity in another. In our study, overall patterns of PFM activity were described, but no conclusions can be drawn due to lack of specificity e.g. decreasing PFM activity on the left with increasing PFM activity on the right would appear relatively flat. The only technology that does allow us to differentiate *i.* left from right *ii.* front from back *iii.* superficial from deep is the MAPLe (Multiple Array Probe Leiden) (78), which can't be used in dynamic weightbearing positions due to probe geometry. Current measurement options do not allow for differentiation of PFMs during gait.

Despite these shortfalls, EMG of the PFMs during gait is sensitive enough to identify individual variations in range, amplitude and wave pattern (Chapter 3). In our study, there was wide range of PFM EMG variability during gait between subjects, indicating different strategies involving involuntary PFM activation. However, there was low variation within subjects, indicating consistent subject-specific patterns of involuntary PFM activity during gait.

Whilst at least 44 studies have measured the PFMs during weightbearing, and at least 12 have done so during dynamic weightbearing activities, only five have reported on PFM data captured during gait or a phase thereof (Chapter 2). Two studies described characteristics of PFM EMG activity during running (17,18). One study reported on PFM EMG during single leg stepping (14), and two presented vaginal pressure data during walking and dynamic activities (15,16). This is the first study that investigates and describes the impact of the various weightbearing phases of the gait cycle on involuntary PFM activity.

The aims of this thesis were to establish current practise in measuring the PFMs during gait and weightbearing (scoping review) and to describe PFM activity during gait with respect to the various weightbearing phases of the gait cycle (primary study).

The scoping review (Chapter 2) identified a range of measurement modalities, tools and applications. It further identified populations under investigation, and noted that research describing normal PFM function was conducted in healthy subjects. The impact of weightbearing on PFM function, and its relationship with pelvic dysfunction in clinically relevant populations was investigated in numerous studies (19,21,27,35,36,36,37,46,65,68,76). However, best practise could not be established, with only five studies published describing PFM activity during gait (14-18). Four of the five studies were concerned with reliability (17,18) or feasibility (15,16) testing. A degree of methodological consistency emerged – gait studies investigated in healthy subjects, with empty bladders, established a Base Level in standing prior to testing, and cueing was verbal (verbal and visual in one study (14). Four of the five studies were in females, and one presented data on the male PFMs (14). However, no gold standard could be identified.

The PFMs are a complex group of muscles, with the female PFMs being particularly vulnerable. Different measurement modalities reported on varying aspects of their function. EMG described electrical activity; pressure modalities reported on abdomino-pelvic pressure data which was correlated with PFM strength; and ultrasound identified visual parameters of PFM displacement. Manual assessment provided insights regarding strength, endurance, tone, symmetry, and pain. Female PFMs are investigated more than male PFMs, and adults outnumber children.

The scoping review also identified literature gaps regarding PFM activity during gait namely: *i.* no published literature describing normal parameters of PFM function during gait; *ii.* very little published literature on male PFMs; *iii.* lack of appropriate technology and terminology to describe different areas of the PFMs; iv. the role of bladder volume on PFM activation. The scoping review further identified that current research into PFM function during weightbearing activities is almost exclusively a first world initiative.

The results of the primary study (Chapter 3) are consistent with Luginbuehl et al in describing periodic characteristics of PFM activity during gait (17). However, whilst they reported on PFM EMG data gathered from 10 consecutive steps of the right lower limb during running (which excludes a double support phase), we reported on PFM EMG data from both lower limbs, with respect to single or double support. Our results show low intra-subject, but high inter-subject, variability. This involuntary PFM activity during gait which in some cases exceeds 100% MVC in standing, appears to decrease with age and be affected by lower limb specifics. Involuntary activity is established before voluntary activity through learning to walk then achieving continence. A voluntary awareness of, and relationship with, the PFMs usually occurs as a consequence of and for childbirth. Differences due to parity, hormonal status, age, gender and pain status need to be investigated.

The PFMs are a complex and highly vulnerable structure (10), consisting of multiple individual muscles (41) and associated connective tissue, both musculoskeletal and musculovisceral. This connective tissue has been found to be at least three times that of other skeletal muscles (101). Diagnostic descriptors of the PFMs are based on activity and anatomical area e.g. contraction vs. relaxation, voluntary vs. involuntary, superficial vs. deep, anterior vs. posterior, left vs. right (7). The wave pattern of PFM activity seen during gait is a combination of all PFM EMG activity. It is likely to be due to a variable contribution from different PFMs at different stages of the gait cycle, potentially based on weightbearing.

We have presented a case for differential lower limb involuntary PFM activity, based on weightbearing. We propose that unilateral PFM function, as found during gait and dynamic activities, is the subject of further investigation.

4.2. Clinical implications

Developmentally, gait is achieved before control of bladder and bowel is established (102). The PFMs respond to the increasing locomotor demands and societal expectations of continence, albeit involuntarily. PFM activity is largely involuntary for most males, children and nulliparous females.

Voluntary PFM activation is bilateral, in the absence of focal pathology. Involuntary PFM activity, be it a contraction or relaxation, is described in relation to bladder, bowel and sexual function – do the PFMs work reflexively with a cough (46), do they let go to pass stool (10), or do they spasm in the guarding reflex of vaginismus (43)? These involuntary actions involve bilateral PFM function.

However, when managing pain in the sporting (9) or pregnant pelvis (11), dysfunction often presents unilaterally. This is an indicator of the stressors and challenges experienced by the pelvis during dynamic activities be they high performance e.g. gymnastics or football; or ADLs e.g. walking, climbing stairs, standing to dress, or getting in/out of the bath or car. Differences in PFM activity during gait are seen both with unilateral weightbearing or single support, but also with weight shift and transfer through the pelvis during double support.

Pregnancy and childbirth place significant stress on the female abdomino-pelvis. Activities of daily living (ADLs) can be a challenge for many patients with pelvic girdle pain. Whilst walking is often provocative, additional functions such as carrying and lifting are also impaired (34). Pregnant women are vulnerable, with many experiencing ongoing pain and dysfunction well after delivery; complicated by the physical demands of caring for an infant.

The pelvis has traditionally been divided compartmentally by function, with medical specialities laying claim to a distinct anatomical part of the pelvis. The anterior compartment is the domain of the urologist, the middle compartment is the obstetrician and gynaecologist’s, the posterior compartment belongs to the colorectal surgeon. It is only in recent times that mutual interest in pelvic floor disorders has seen the merging of the front and middle compartments under the umbrella of urogynaecology.

The primary study describes a range of involuntary PFM activity during gait. Even in a seemingly homogenous sample (healthy nulliparous female adults) individual patterns can be seen. This is true for range, amplitude, wave pattern and timing.

This study is unlikely to impact on current practise yet. It lacks sufficient numbers to draw any conclusions. Greater numbers may have allowed for sub-group analysis including the impact of age, pelvic health, BMI, history of low back pain or pelvic pain and lower limb discrepancies on PFM EMG during gait.

4.3. Strengths

4.3.1. Scoping review

Identified strengths of the scoping review include:

- Although originally conducted in August 2014, the scoping review was updated twice; once in Nov 2015 and once in Oct 2016. The 1st update identified an additional two studies; the final update did not identify any further published research.
- The initial search was conducted by a pair of reviewers.

- Six electronic databases were searched – Ebscohost (CINAHL, MEDLINE, SPORTDiscus); Pedro; PubMed; Science Direct; Scopus; and Web of Science – to cover breadth of the research.
- Search terms were structured to include depth of current research, by looking beyond descriptors of gait (walking, running, jumping) to include weightbearing (standing).
- Data was captured in a specifically designed data extraction sheet. This was constantly modified and updated as new studies were captured; due to the heterogeneity of the research available.

4.3.2. Primary study

The following strengths were identified:

- The initial recruitment lecture was piloted on 2nd and 3rd year students, who responded positively to the content.
- Although the primary investigator conducted subject set-up, one gait engineer and/or one gait lab technician was onsite to assist with most data capture. They assessed the PFM EMG signal, and adjusted settings where necessary.
- All subjects completed feedback in the form of Visual Analogue Scales with no complaints from six subjects across six categories (electrode insertion, electrode removal, pain, discomfort, burning, other). One subject rated electrode insertion at 1/10, and another subject rated electrode insertion and removal at 3/10, pain at 1/10, discomfort at 4/10. She indicated she did not require follow up. There were three positive written comments from subjects on the feedback form, and six subjects indicated they would like to be made aware of the results.
- Technological advances which have resulted in the ability to synchronize 3D motion analysis with wireless EMG, allowing for PFM activity to be assessed during functional whole body movements.

4.4. Limitations

4.4.1. Scoping review

Three limitations were identified in the scoping review, namely:

- The initial scoping review was conducted by a pair of reviewers, but the updates were performed by the primary investigator alone.
- Search terms could have been wider to include sports specific terminology, functional whole body movements, and involuntary or reflex PFM contractions. This would have yielded a handful more studies.
- The constantly evolving data extraction sheet meant that classifications kept changing; the most obvious example being in the use of a ‘vaginal probe’ – which differs markedly between EMG, pressure and ultrasound studies

4.4.2. Primary study

Eight limitations were identified in the primary study, namely:

- The primary study struggled to recruit sufficient numbers. The challenge of recruiting for a pelvic study in a healthy nulliparous population was underestimated. By including subjects who had no pelvic dysfunction, they also had no vested interest. Recruiting from populations who have a clinical interest in the study may yield a better sample e.g. women with persistent post-natal pelvic girdle pain, or sportspeople with chronic unilateral pelvic pain.
- A convenience sample was used, due to the difficulty of recruiting subjects for a study using equipment of such a personal nature.

- Lower limb presentations of note should have been an exclusion. Limiting the pain exclusions to 'low back and pelvic pain' didn't account for lower limb dysfunction e.g. hip and lower limb pain. Known leg length discrepancies should also have been excluded.
- A larger sample may have allowed for sub group analysis based on age, BMI, pelvic health status and lower limb presentations of note.
- Due to the low sample size, no concrete conclusions can be drawn, nor can any generalisation be made. There is too much variability in a seemingly homogenous population to infer clinically relevant parameters of PFM EMG during gait.
- In one instance, when neither the gait lab engineer or technician was available, lack of technological knowledge and experience on the part of the primary investigator resulted in one subject with corrupt gait trial data.
- The technological limitation of PFM EMG only providing data on the PFMs as a single entity is an inherent study design fault. There can be no differentiation and separation of PFMs into superficial or deep, anterior or posterior, left or right.
- This study was designed to investigate and describe PFM EMG activity during the various weightbearing phases of the gait cycle. More comprehensive motion analysis data would have provided additional insight into body position and fluctuations or asymmetries in the gait cycle. This was a funding limitation

4.5. Recommendations for future research

The following recommendations are made for further research:

Activity of the PFMs during gait should be investigated to establish normative values for different populations. The primary study should be repeated in parous women matched by age and parity and mode of delivery. It should also be repeated in populations with known lower limb dysfunctions and age & parity matched controls. Bladder volume is an additional variable; whose effect needs to be considered in studies involving PFM activation (99).

Furthermore, additional motion analysis data should be gathered to differentiate between the phases of gait based on stance and swing phase. This will require greater analysis of the lower limb and potentially thorax during gait; necessitating more passive reflective markers and additional analysis at greater expense.

The impact of weightbearing should be investigated by increasing or decreasing the load through the (hemi) pelvis. Walking with crutches (partial weightbearing vs non weightbearing), stair climbing and hopping are all suggested.

A reliable measurement tool should be designed to measure PFM activity during gait. This tool should be able to differentiate activity between superficial / deep, anterior / posterior, and left / right. An inflatable probe, with electrode configuration similar to the MAPLe (78) should be considered. Luginbuehl et al recommended a 3-pol-STIMPON® electrode (Innocept Biobedded Medizintechnik GmbH, Gladbeck, Germany) in a differential configuration to minimise crosstalk. They suggested that due to its smaller electrodes and total insertion into the vagina, it adapts its shape individually to the vaginal cavity (18). However, at the time of testing and writing, no vaginal electrode was available on their website[1].

4.6. Conclusion

Successful research consists of a series of checks and balances, to ensure research quality and protect subjects.

[1] http://www.innocept.de

Measurements of the PFMs during gait are in their infancy. Involuntary PFM activity exists during walking and dynamic weightbearing activities. Current technological options do not allow us to differentiate between individual PFMs during gait or dynamic activities due to probe geometry or electrode configuration. However, differences in PFMs have been recorded in non-weightbearing positions. The development of an electrode capable of differentiating between involuntary activity from various PFMs during gait would improve understanding into the complexity of pelvic function when physically active.

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Addenda

Addendum A Search Strategy for each database

Ebscohost (CINAHL, MEDLINE, SPORTDiscus)

("pelvic floor muscle" OR "pelvic floor muscles" OR "pelvic floor")
#1 AND (gait OR running OR walking OR jumping OR "weight bearing" OR standing)

Search at: Subject terms

Pedro

("pelvic floor muscle" OR "pelvic floor muscles" OR "pelvic floor")
#1 AND (gait OR running OR walking OR jumping OR "weight bearing" OR standing)

PubMed

("pelvic floor muscle" OR "pelvic floor muscles" OR "pelvic floor")
#1 AND (gait OR running OR walking OR jumping OR "weight bearing" OR standing)

Filter: human

Including MeSH terms

Science Direct

("pelvic floor muscle" OR "pelvic floor muscles" OR "pelvic floor")
#1 AND (gait OR running OR walking OR jumping OR "weight bearing" OR standing)

Search at: Abstract, title, keyword

Scopus

("pelvic floor muscle" OR "pelvic floor muscles" OR "pelvic floor")
#1 AND (gait OR running OR walking OR jumping OR "weight bearing" OR standing)

Search at: Article title, abstract, keyword
Limit to: human(s)

Web of Science

("pelvic floor muscle" OR "pelvic floor muscles" OR "pelvic floor")
#1 AND (gait OR running OR walking OR jumping OR "weight bearing" OR standing)

Addendum B Custom Data Extraction Sheet

Data Extraction Scoping Review.xlsx

Addendum C Journal Submission Guidelines for International Urogynaecology Journal (IUJ)

Original Articles (primary study – Chapter Three)

Title page:

- all authors and affiliations
- corresponding author contact information (email mandatory)
- conflict of interest statement for each author
- each author's participation in the manuscript

Structured abstract (250 words)

Keywords (up to 6)

Brief Summary (25 words)

Word limit of 4000 words (average is 2000 words)

Maximum of:

- 6 authors (more than 6 authors requires submission of a letter to the editorial office explaining the reasons)
- 30 references
- 6 figures/tables (If the article contains a large number of illustrations then the length of the text should be adjusted accordingly to a lower word count)

Review Articles (scoping review – Chapter Two)

Title page:

- all authors and affiliations
- corresponding author contact information (email mandatory)
- conflict of interest statement for each author
- each author's participation in the manuscript

Structured abstract (250 words)

Keywords (up to 6)

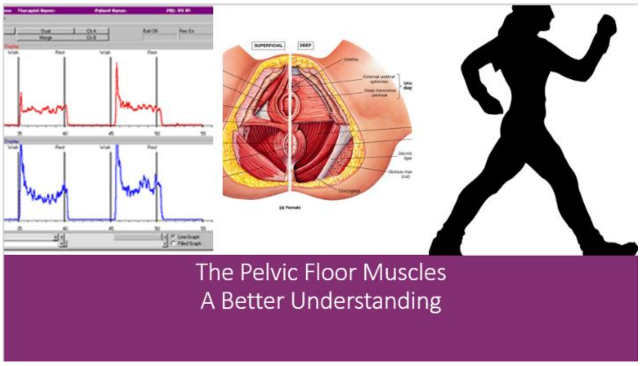
Brief Summary (25 words)

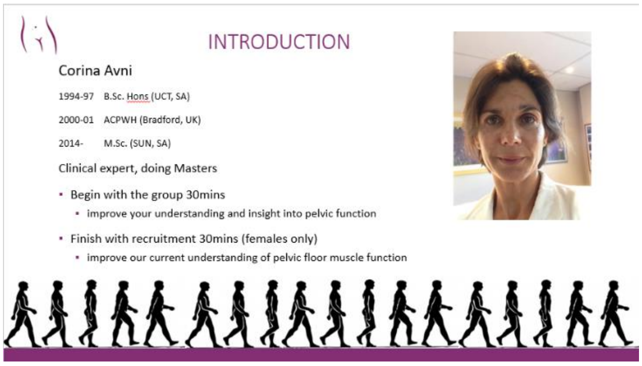
Word limit of 6000 words

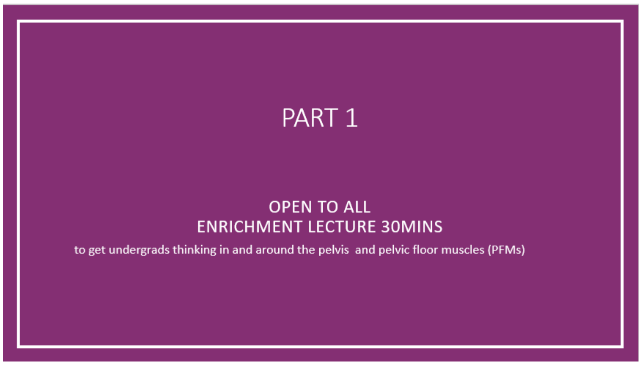
Maximum of:

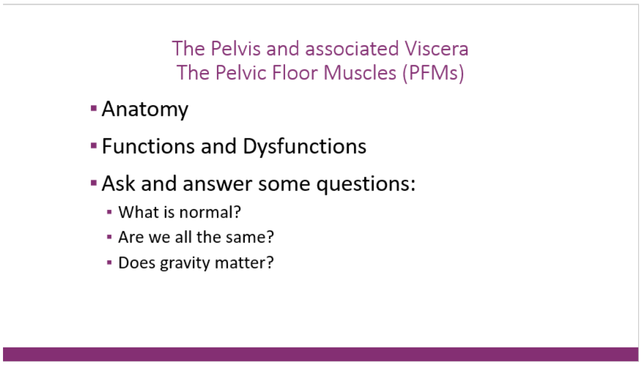
- 6 authors
- 100 references
- 10 figures

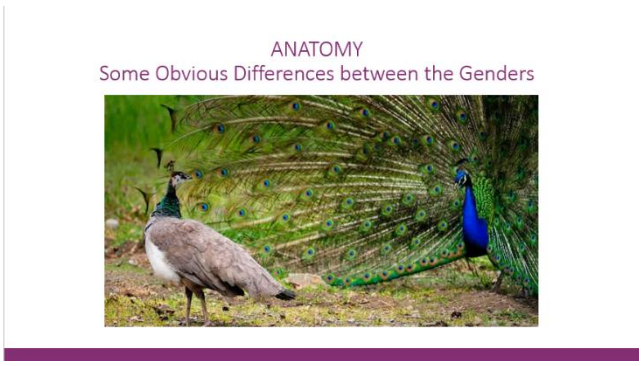
Addendum D Recruitment Lecture

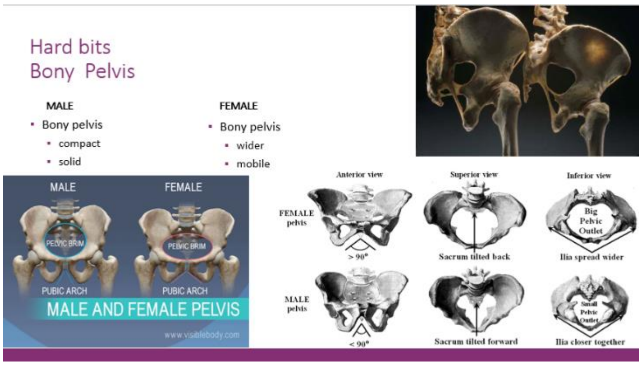


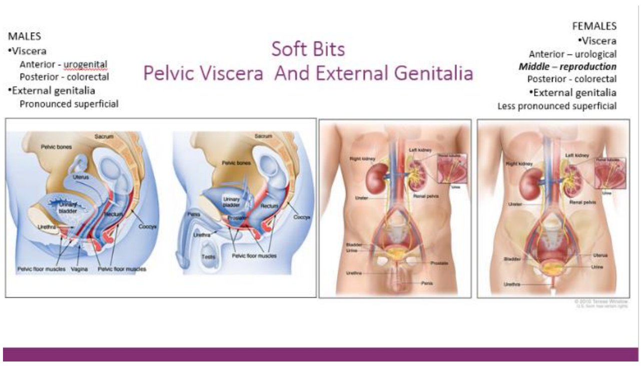


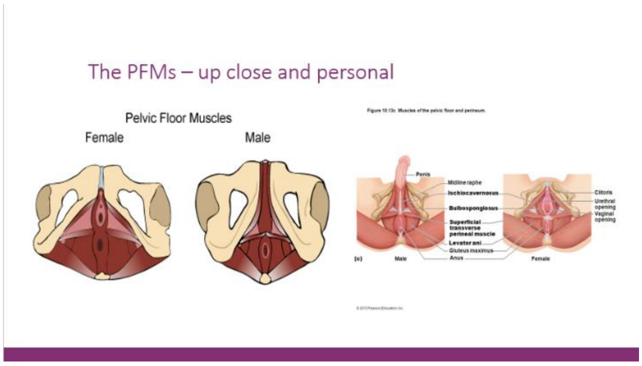


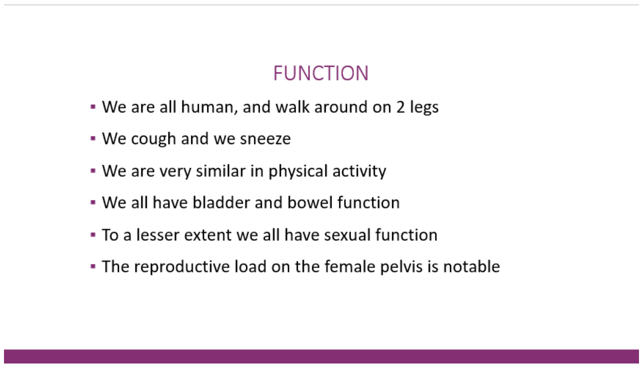












The Functions Of The Bony Pelvis

- **LOCOMOTION**
  - Weight bearing – when upright/against gravity
  - Weight transfer – from one side to the other (during walking)
  - Protect viscera
- **REPRODUCTION**
  - *(in females)*
- Needs to be 'big and loose enough' for childbirth (to pass the fetal head....)
  - OBSTETRIC DILEMMA
    - Vulnerability of human infant at birth (vs other animals)
  - BIPEDALISM VS BIRTH VS BRAINS
    - Encephalisation vs. pelvic outlet

The Functions Of Viscera And Genitalia

- **Bladder**
- Elimination
- Storage – 99%
- Voiding – 1%

- **Bowel**
- Elimination
- Evacuation – 3xpd-3xpw
- Storage
  - Colon
  - Rectum is transit organ

- **Sexual**
- ***Reproduction***
- Pleasure

The Many Functions Of The PFMs

Musculoskeletal	Bladder	Bowel	Sex	Support normally a female complaint
Spinal and pelvic stability	Closing the urethra	Anal closure for continence	Sensory awareness	Pelvic Organ Prolapse
Control of intra-abdominal pressure	Inhibiting the bladder	Anal release for evacuation	Orgasmic potential	

What Is Normal?

TIGHT?
- Benefits – greater rigidity and stability with force
- Complications – rigidity, stiffness, difficult passage through the pelvis

LOOSE?
- Benefits – easier passage of movement through the pelvis, and of the pelvis?
- Complications – too loose, things falling out under the effect of gravity

	PFMs	Bladder Function	Bowel Function	Musculoskeletal
Too tight				
Too loose				

The Current Accepted Paradigm

- **We are all long lax and loose**
- **....and we all need to do 100 Kegels or pelvic floor exercises (PFEs) a day.**
- Who might need to do PFEs?

Are We All The Same??

- Athletes?
  - Some leak urine
  - Is it because they are loose...
  - ...or doing impact/load activities?
- Men?
  - Are they loose or tight?
  - Think of the prostate....
- And younger women/ teenagers?

Letting Go...

When do you need your PFMs to let go?

For movement through the pelvis....

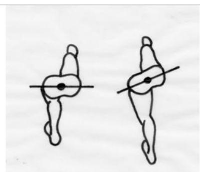
...To wee and poo...

...To use tampons and have sex...

During childbirth, do we squeeze or let go....?

What about for movement of the pelvis itself – squeeze or let go?

Movement And The Pelvis



- Contraction and relaxation – Messelink 2005
  - Contracting relaxing PF – normal function
  - Contracting non-relaxing PF – pain, hypertonic conditions
  - Non-contracting relaxing PF – supportive dysfunctions
  - Non-contracting non-relaxing PF – no function
- Movement in the pelvis (when the pelvis is still) – intra-pelvic movement
- Movement in the pelvis (when the pelvis is moving) – pelvic movement

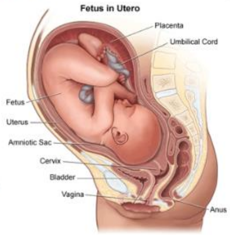
Of course, when your body has done this....

more than once....

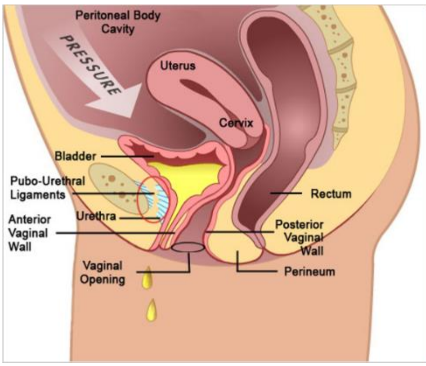
Everything has to move...

Singleton pregnancy at 37 weeks

Fetus in Utero

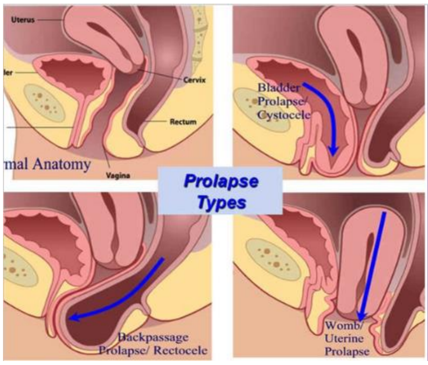


Twin pregnancy at 28 weeks



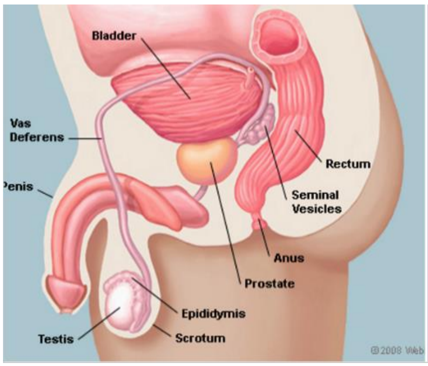
You can expect connective tissue will have stretched and/or broken...

...Female



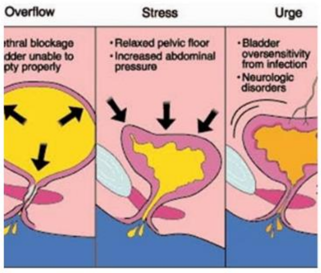
You can expect some disturbing Pelvic Organ Prolapse

The role of the PFMs in managing laxity is well researched....



See the tighter narrower longer system?

...Male



But that's not the only cause of leakage....

Blockage (mostly but not exclusively male)

overflow

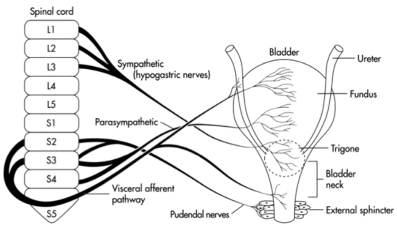
Biomechanical (mostly but not exclusively female)

stress incontinence

post micturition dribble

Irritative neurological (behavioural; population dependant....)

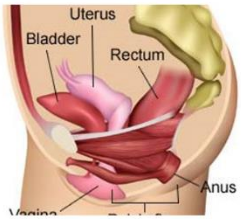
over active bladder



And don't forget the neurology

This happens to be the bladder

Never forget the ***bowel***



Multi-functional Muscle activity

- It's the Swedish Olympic trampoline team

Prevalence of stress incontinence in nulliparous elite trampolinists

K. Eliasson, T. Larsson and E. Mattsson

SCANDINAVIAN JOURNAL OF MEDICINE & SCIENCE IN SPORTS

VOLUME 12, ISSUE 2,

PAGES 106–110, APRIL 2002

- **Keywords:**
  - female stress urinary incontinence; pad test; perineometer; trampoline training
- During trampoline jumping the pelvic floor is exposed to high forces. There has been a general belief that physically fit women have a strong pelvic floor as a result of their regular training, thus preventing urinary incontinence.
- The aim of this study was to survey the prevalence of stress urinary incontinence in female elite trampolinists. The prevalence of urinary incontinence was assessed by a questionnaire, sent to all 35 elite trampolinists (mean age 15, range 12–22 years) in Sweden.
- Eighty percent of the trampolinists reported involuntary urinary leakage, but only during trampoline training. The leakage started after 2.5 (range 1–4) years of training. Age ($P < 0.001$), duration of training ($P = 0.04$), and training frequency ($P = 0.01$) were significantly associated with leakage.
- All women above 15 years of age ($n = 23$) reported urinary leakage ($P < 0.001$). Eighteen incontinent women continued the study and their leakage was verified by a pad test. The leakage averaged 28 g during a jump session.
- The muscle strength was measured with perineometry in 10 women and showed good strength in the pelvic floor muscles.

Gravity – Does it matter?

- Pelvic dysfunction more likely
  - In standing
  - Than sitting or lying
- The role of gravity in the now
- The role of gravity over time

Exposure At Undergrad (Physio)

- Nothing to the PFMs themselves
- Some are exposed to aspects of Women's Health Physio (Antenatal Postnatal; gynae surgery?)
- All of the exposure is in the context of PFEs:
  - the core
  - Strengthen
  - tighten

Exposure At Postgrad (Physio)

- WHPG was fastest growing SIG for awhile (overtaken by Pain)
- OMT is coming for the PF (low back and pelvic pain)
- Sports is coming for the PF (groin and hamstring injuries)
- Cardiothoracics are coming for the PF (IAP and coughing)
- Paeds should be coming for the PF (constipation bed wetting and continence)
- Pain with a stress response that effects the autonomic nervous system and hence the viscera is coming for the PF
- Exercise therapies(Pilates, yoga, Tai Chi etc) are coming for the PF (the core)

PART 2

OPEN TO FEMALES, AGE 20 AND UP
RECRUITMENT SESSION

A description of the electromyographic activity of the pelvic floor muscles in healthy nulliparous female adults during the various weightbearing phases of the gait cycle

Motivation For Enquiry

- 2014 - Cadaveric study
- Into the architectural design of the PFMs that found that their design is consistent with muscle sub-specialization
- By examining the size and volume of the various PFMs, they were able to conclude that
  - *"PFM design shows individual muscles demonstrating differential architecture, corresponding to specialized function in the pelvic floor"*
- DIFFERENT PFMs FOR DIFFERENT FUNCTIONAL DEMANDS

...further motivation...

- Another cadaveric study…. …concluded that:

- *"In females, pelvic floor muscles have the capacity to increase stiffness of the pelvic ring.*
- *In addition, these muscles can generate a backward rotation of the sacrum in both sexes."*

Clinical interest/ motivation

- Clinically
  - Unilateral tightness in a case of deep gluteal pain
    - *Subsequent resolution of symptoms upon releasing identified muscle tightness*

- Indicated that the 2 sides (left and right) of the pfms can differ, and cause clinically significant symptoms

Before going further - who do I need?

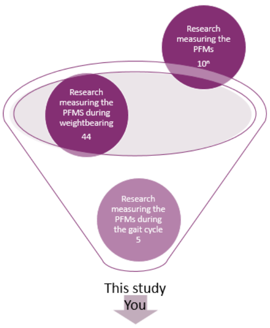
- Women, age 20 and up.
  - Teens are excluded to protect them

Who do I not need?

- Women who have been pregnant (potentially loose)
  - 1st of its kind study and trying to limit pregnancy and labour as confounders
  - Also electrode fits differently in the pelvis of a women who has been pregnant
- Women who have difficulty with penetrative events (potentially tight)
  - No virgins. This should not be a person's first contact with work of this kind.
  - No-one who cannot insert a tampon.
- Women with low back pain or pelvic pain (Dysfunction musculoskeletal)
  - The electrode, whilst harmless, is not indicated in all patient groups. If you have current low back or pelvic pain, or a history of, for your comfort and protection, please don't volunteer
- Women with moderate to severe bladder, bowel and/or sexual dysfunction (Dysfunction PFM and viscera)
  - Again, if YOU know you have problems, the study would not want to cause undue harm by treating you the individual as anything less than a vulnerable patient, rather than a study subject

How are the PFMs measured during gait and weight bearing?

- Scoping review August 2014 (human, measure PFMs, weightbearing position)
- Repeated Nov 2015
- 6 databases
- 549 hits (plus recent – still have to check duplicates etc)
- 44 articles reported on measurements taken of the PFMs in an upright position.
- 5 were during gait
  - 2 used EMG whilst running
  - 2 looked at pressure whilst walking and carrying
  - 1 reported on PFM activity and pressure during a single leg step



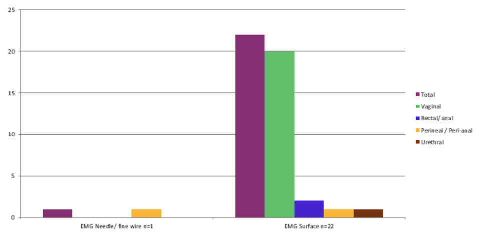
AN IDEA OF THE SIZE OF THE GAP IN THE LITERATURE

What happens in the pelvis during normal human locomotion, or bipedal mobility?

EMG

- Surface electrodes 95% of the time
- Fine-wire in one case
  - anaesthetized patients who were raised into a vertical position so as to check the effect of gravity on the myoelectric activity of the PFMs with gravity!!
- *18/21 (86%) – vagina*
- 3/21 (8%) – ano-rectum
- 1/21 – braved the (male) urethra

EMG investigations into the PFMs



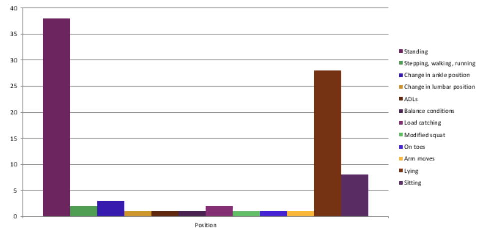
OTHER MEASUREMENT TOOLS

- Pressure 18/44
- US 12/44
- Manual Assessment 8/44

OTHER MEASUREMENT MODALITIES

- Other equipment used in these studies include
  - Biofeedback
  - adjustable blocks/wooden platform
  - ***Questionnaires***
  - Accelerometry
  - Inclinometry
  - Fluoroscopy
  - ***motion analysis***
  - static proctography
  - pad test
  - peak respiratory flow rate!

TESTING Positions IN WHICH THE PFMS HAVE BEEN MEASURED



This study is going to use EMG

- Internal surface vaginal electrode
- Periform

This study is going to use Gait or Motion Analysis

- Heel toe ONLY markers
- Please wear comfortable loose fitting clothing
  - Tracksuit pants are perfect
  - Jeans are not
  - A skirt is welcome
- You will have data capture equipment attached to you with tape, and will carry a small transmitter

- You will insert the electrode yourself.
- You will do a few PFM contractions.
- You will walk 3 times the length of the 3D motion capture area.

Additional data

- Australian Pelvic Floor Questionnaire
- Height and weight for BMI

- Please volunteer.

- **Female subjects** standardized sample
- Min n=15 Max n=50 (funding)
- Healthy subjects
  - to minimise risk to study subjects if known dysfunction

- If volunteering, please complete the contact and eligibility forms

- If you are eligible, you will be contacted offering you an appointment at the 3D Motion Analysis Lab to participate (in liaison with the department)

PLEASE DON'T VOLUNTEER IF:

- You are not yet 20 years old
- You have been pregnant
- You are a virgin or experience difficulty with indwelling sanitary products
- You have significant bladder bowel or sexual dysfunction
- You have low back pain or pelvic pain
  - either current, or a history of

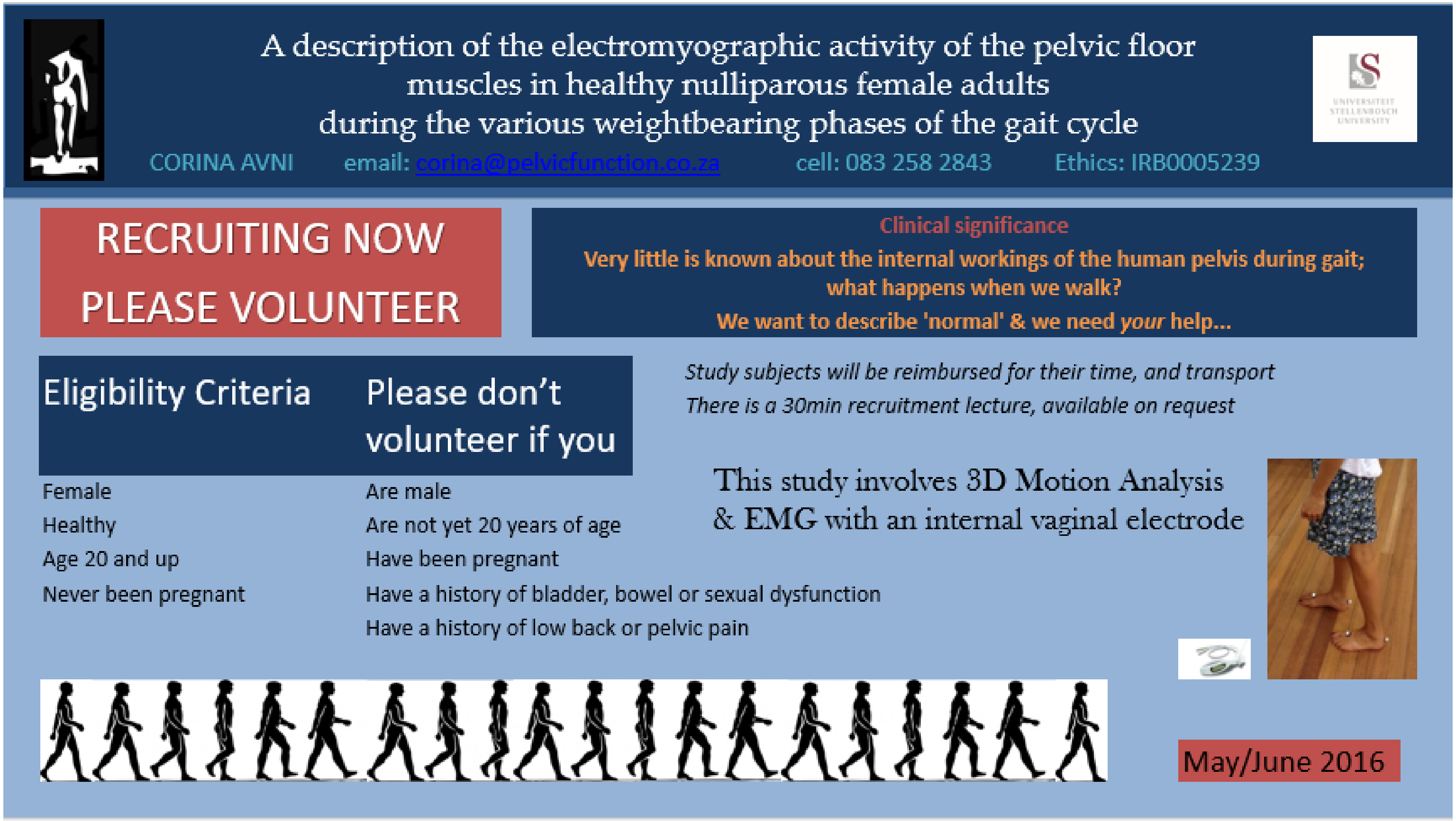
THANK YOU
for your TIME and ATTENTION

All eligible volunteers, please take a moment to complete

The Volunteer Eligibility Form

PAYMENT R50 (Double minimum wage)
PLUS R3.50 per km travel (if off site)

Addendum E Recruitment Poster



Addendum F Critical Appraisal Tool for descriptive and cross-sectional studies

11 questions to help you make sense of descriptive/cross-sectional studies

How to use this appraisal tool

Three broad issues need to be considered when appraising the report of a descriptive/ cross-sectional study (e.g., a study that collects data on individuals at one time point using a survey or review of medical charts):

- Are the results of the study valid?
- What are the results?
- Will the results help locally?

The 11 questions on the following pages are designed to help you think about these issues systematically. The first two questions are screening questions and can be answered quickly. If the answer to both is "yes", it is worth proceeding with the remaining questions. You are asked to record a "yes", "no" or "can't tell" to most of the questions. A number of italicized prompts are given after each question. These are designed to remind you why the question is important. Record your reasons for your answers in the spaces provided. These questions are adapted from Guyatt GH, Sackett DL, and Cook DJ, Users' guides to the medical literature. II. How to use an article about therapy or prevention. JAMA 1993; 270 (21): 2598-2601 and JAMA 1994; 271(1): 59-63 © Milton Keynes Primary Care Trust 2002. All rights reserved.

Screening Questions

1. Did the study address a clearly focused issue? Yes Can't tell No

HINT: A question can be focused in terms of: – the population(s) studied – the health measure(s) studied (e.g., risk factor, preventive behaviour, outcome)

2. Did the authors use an appropriate method to answer their question? Yes Can't tell No

HINT: Consider - Is a descriptive/cross-sectional study an appropriate way of answering the question? - Did it address the study question?

Detailed Questions

3. Were the subjects recruited in an acceptable way? Yes Can't tell No

HINT: We are looking for selection bias which might compromise the generalizability of the findings: - Was the sample representative of a defined population? - Was everybody included who should have been included?

4. Were the measures accurately measured to reduce bias? Yes Can't tell No

HINT: We are looking for measurement or classification bias: - Did they use subjective or objective measurements? - Do the measures truly reflect what you want them to (have they been validated)?

5. Were the data collected in a way that addressed the research issue? Yes Can't tell No

Consider: – if the setting for data collection was justified – if it is clear how data were collected (e.g., interview, questionnaire, chart review) – if the researcher has justified the methods chosen – if the researcher has made the methods explicit (e.g. for interview method, is there an indication of how interviews were conducted?)

6. Did the study have enough participants to minimize the play of chance? Yes Can't tell No

Consider: – if the result is precise enough to make a decision – if there is a power calculation. This will estimate how many subjects are needed to produce a reliable estimate of the measure(s) of interest.

7. How are the results presented and what is the main result? Yes Can't tell No

Consider: – if, for example, the results are presented as a proportion of people experiencing an outcome, such as risks, or as a measurement, such as mean or median differences, or as survival curves and hazards – how large this size of result is and how meaningful it is – how you would sum up the bottom-line result of the trial in one sentence

8. Was the data analysis sufficiently rigorous? Yes Can’t tell No

Consider: – if there is an in-depth description of the analysis process – if sufficient data are presented to support the findings

9. Is there a clear statement of findings? Yes Can’t tell No

Consider: – if the findings are explicit – if there is adequate discussion of the evidence both for and against the researchers’ arguments – if the researcher have discussed the credibility of their findings – if the findings are discussed in relation to the original research questions

10. Can the results be applied to the local population? Yes Can’t tell No

HINT: Consider whether - The subjects covered in the study could be sufficiently different from your population to cause concern. - Your local setting is likely to differ much from that of the study

11. How valuable is the research? write comments here

Consider: – if the researcher discusses the contribution the study makes to existing knowledge (e.g. do they consider the findings in relation to current practice or policy, or relevant research-based literature?) –if the researchers have discussed whether or how the findings can be transferred to other populations

TITLE OF THE RESEARCH PROJECT: *A description of the electromyographic activity of the pelvic floor muscles in healthy nulliparous female adults during the various weightbearing phases of the gait cycle.*

ETHICS REFERENCE #: S15/08/170

PRINCIPAL INVESTIGATOR: **Corina Avni**

ADDRESS: *Removed for publication*

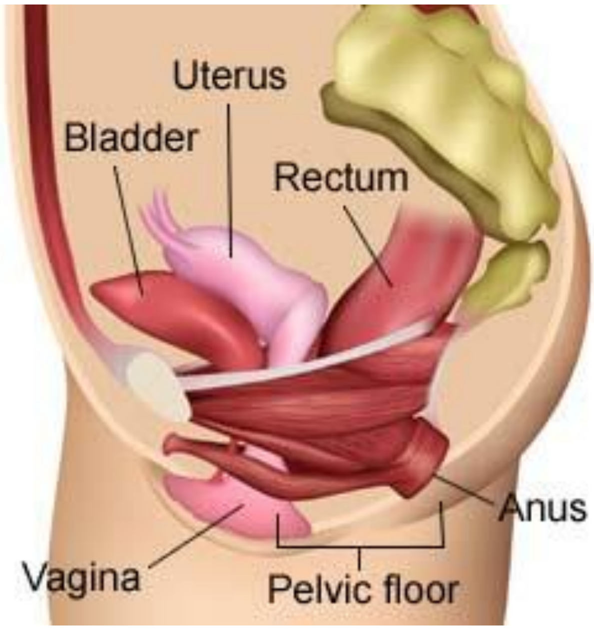
CONTACT NUMBER: *Removed for publication*

CONTACT EMAIL: *Removed for publication*

You are being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff or doctor any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

*This study has been approved by the **Health Research Ethics Committee at Stellenbosch University** and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.*

What is this research study all about?



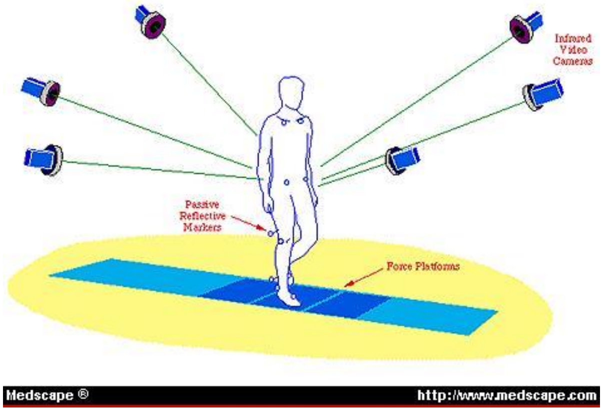
The pelvic floor muscles are that group of muscles inside the pelvis that run from the pubic bone at the front to the sacrum and coccyx at the back. They form your ‘under-carriage’ and are like a sling or hammock through which passage is required.

They control movement through the area; specifically, movement of waste (urine and faces) and reproductive (semen, menstrual flow, or an infant) products. They are often studied in their context of bladder, bowel and sexual function, but seldom researched during dynamic moving activities.

This study aims to describe, for the first time, the electromyographic activity of the pelvic floor muscles during gait, or walking.

It will do so using the current gold standard in technology for measuring both the PFMs (Periform internal surface electrode) and gait (VICON).

It will be conducted at the 3D Motion Analysis Laboratory at Tygerberg Hospital, Teaching Block, 1st Floor.



The total number of participants will be reliant upon

1. the number of volunteers
2. who are eligible
3. consent to the study procedure
4. and are able to self-insert the internal surface electrode.

A minimum of 15 participants is required for statistical purposes; funding will limit the study to less than 50.

All research to date has either been done in a non-weightbearing position, or looks at the PFMs in weightbearing, when both sides squeeze together (as for bladder and bowel control). This study is interested in the impact of moving whilst weightbearing on activity of the PFMs.

If you consent you will undergo the following procedure:

NB all set-up and data capture is performed by the primary investigator – Corina Avni

Step 1 – Pre-test Procedure

You will be given an appointment at the 3D Motion Analysis Lab at Stellenbosch University

You will be greeted, and asked to confirm your demographic details

You will receive a standard explanation of:

- Set-up
- Test procedure
- After the test procedure

After the explanation, you will be asked to:

- Confirm informed consent on the day
- Complete the Australian Pelvic Health Questionnaire (self-administered)
- empty the bladder in the bathroom
- return to the lab and remove your shoes

You will then be measured:

- ➢ height
- ➢ weight
    - o to calculate and confirm your BMI

You will be set-up with sticky reflective VICON markers (heel and toe)

You will be set-up with an EMG adaptor stuck to the inside of your left hip with double sided tape.

You will be set-up with an EMG data capture unit, worn in a small pouch around your waist

You will be set-up with a ground electrode stuck to the inside of your right hip with double sided tape.

You will then be given a standard explanation **regarding self-insertion of an internal vaginal electrode** (no bigger than an erection, and smaller than a speculum at the Gynae ….)

You will be taken to a private secure area for self-insertion of the electrode. The electrode is worn under clothing, limiting the impact of nudity or undue bodily exposure. Self-insertion is done after all the other set-up tasks, to minimize the time between electrode insertion and test procedure

You will then be connected; the internal electrode will be connected to the EMG adapter

You will be given brief written instruction to walk freely and comfortably, after performing a few PFM contractions to establish a baseline.

<u>Step 2 – Test Procedure:</u>

Perform a base level of PFM activity including:

- ➢ Thirty (30) seconds at rest in standing
- ➢ Two (2) PFCs at MVC for 5secs each, 10sec rest between
- ➢ One (1) PFC sub maximal for 20secs

Perform walking test

- ➢ Walk three (3) times the length of VICON data capture area at self-selected brisk but easy pace

<u>Step 3 – Post Test Procedure:</u>

You will be detached from all the external data capture equipment

You will return to the private area for self-removal of the electrode. You will place the used electrode in a bin provided, for appropriate disposal. It is 'single patient multi-use' so it cannot be reused on another individual

You will dress

You will be invited to complete a feedback form including:

- ➢ response to procedure
- ➢ interest in results

Why have you been invited to participate?

The world does not yet understand the significance of weightbearing through the hemi-pelvis, such as you would when you stood on one leg, as found during the gait cycle. You represent the easiest to test sample for a variety of reasons:

1. The pelvic floor muscles differ greatly between individuals

2. The genders have obvious differences. There is easier access to the female PFMs due to the vagina.
3. Women who have been pregnant have changes in their PFMs, irrespective of the mode of delivery.

You have been selected, as you have the PFMs with the least likelihood of dysfunction; hence you potentially represent 'normal PFM function' at its most simple.

Also, women who have been pregnant might find the electrode moves in the vagina, hence compromising the integrity of the EMG data. The electrode is unlikely to move much at all inside you when you walk.

Due to the limited exposure at undergrad level, it also offers the opportunity to gain practical experience in an increasingly popular field.

What will your responsibilities be?

You will be required to confirm your attendance at a specified appointment at the 3D Motion Analysis Lab.

You will need to attend that session, and confirm consent and your demographic data.

You need to have your height and weight measured, to confirm BMI.

You need to undergo the set-up (previously detailed).

You must be able to self-insert the electrode.

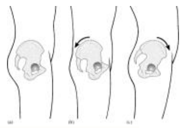
You must complete the baseline and test procedures.

You will be given an opportunity to feedback afterwards, should you so desire.

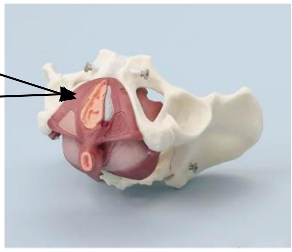
You must stop the proceedings if you are uncomfortable.

Demonstration of Electrode Self-Insertion

The following verbal description is to be accompanied by the primary investigator demonstrating on a model of the pelvis complete with the pelvic floor muscles, and with the electrode.



1. This is your pelvis. It is not aligned like this or this, but like this in standing.
2. This is the part you think of as your pelvic floor; or the 'under carriage'. It is superficial and mostly to the front or anterior.
3. This is your deep posterior pelvic floor.
4. Looking inside, the yellow hole is where the urine comes out at the front (urethra), the square hole in the middle is the vagina, and you can see the anus at the back.



5. This is the probe, or electrode. It is sealed in this plastic bag. It is a single patient multi-use electrode, so *you* could use it again, but we can't use it on anyone else.
6. You will go into our private area. You will undress the bottom half of the body; you will remove your shoes and lower garments (pants or skirt and underwear).

7. You will open the plastic bag and remove the electrode. You will unwind the wire that holds the cables together. There are gloves available should you prefer.
8. You will hold the electrode sideways, and place a small amount (the size of a 50c piece) of KY jelly over the blunt leading end or edge.
9. You will recline as preferred, some prefer lying on their side, others prefer standing with one leg raised and resting on the small footstool provided. Do not tuck your tail bone under, as that is a closed position; rather stick your tail bone out behind you.
10. Using the end of the electrode, gently separate the labia (or lips) in a front-back-front direction. Have the electrodes aligned front/back in the beginning. You will rotate or turn the probe so that one electrode is on the left and one is on the right, during insertion.
11. Continue to breathe lightly and gently into the abdomen (tummy breaths)
12. Squeeze your pelvic floor muscles - stop a wind, use your sex muscles, and stop a wee, all at once.
13. Let go your pelvic floor muscles - let go as though you want to let off wind, or pull out a tampon, or wee in the bath.
14. Continue to breathe.
15. Gently push and twist the probe so that the electrodes sink inwards are align left-right. There might be initial resistance, but the probe is no bigger than an erect penis, hence it should not be an issue once past the PFMs. *THAT SAID: there are some individuals who find it too invasive. If it is sore and a gentle push doesn't help, then you are not obliged to continue with the study. Don't force anything. If unable to insert electrode, approach the primary investigator and you will be offered some explanations as to why you might have struggled etc. Some individuals find them difficult to get in, but once in they are well tolerated. If you become uncomfortable during the test procedure, alert the primary investigator and we will discontinue the testing*

16. When inserted, reach down and check. The end of the electrode with the cables will be there. Check that the cables are left and right, rather than front and back as they were before insertion i.e. the electrode has turned through 90°. Give a gentle push and pull, to make sure it is seated most comfortably.
17. Wipe hands on kitchen roll provided or remove glove. Dispose paper and glove in the red plastic bag provided.
18. Put on your lower garments, excluding shoes and underwear.
19. Make sure the cables are sticking out at waist/belly button.

    Exit private area and approach the primary investigator for final connection to the EMG unit

From the Periform Instruction Manual:

NB: this electrode is sold directly to the public. These are the instructions they provide to customers. They are deemed appropriate, acceptable and sufficient.

IMPORTANT: • Before first and subsequent use wash and dry as directed. • Apply light coating of KY Gel or similar lubricating gel to tip and metal surfaces of probe to aid insertion and provide good electrode conductivity. • Insert into vagina in 'East/West' position, i.e. electrode surface facing towards hips; the external 'flange' should sit comfortably between the labia. • Ensure equipment is turned off before connecting to probe cables. • Use as directed by your medical adviser. After use, turn off equipment, disconnect cables. Do not pull on cables to remove probe. • Wash, dry and store as instructed.

Will you benefit from taking part in this research?

Although there might be no direct personal benefit to you, the study paves the way to create a new paradigm and understanding of pelvic function. If the PFMs are understood to act and react differently with weightbearing, it will change the current concept of PFM rehab for bladder bowel and sexual dysfunction, and many pelvic pain patients including pregnancy related pelvic girdle pain.

You can contribute to shaping our future insight. Without you, this study would not be possible.

Are there in risks involved in your taking part in this research?

There is a small risk that someone who has no bladder, bowel or sexual dysfunction might still not be able to insert the electrode. This is not to be viewed as a dysfunction on the part of the subject, but simply that we are not all the same.

All electrodes will be discarded as per universal precautions. NB No electrodes will be re-used.

There is no risk of infection; although individuals who get vaginal thrush after penetrative events might find they are sensitive after this penetrative event.

There is also a small risk that someone inserts the electrode correctly and completes the study, only to find that they have an emotional reaction to the study afterwards.

If you do not agree to take part, what alternatives do you have?

As this is a descriptive study in a healthy 'normal' population, no intervention or treatment is indicated.

If you feel that the study has made you aware of any pelvic issues you might have, please contact the Western Cape branch of the South African Society of Physiotherapy (SASP) to find a Women's Health physio in your area, who might assess and assist you.

Who will have access to your medical records?

No-one will have access to any of your records.

The only information we will have is your age, height weight and BMI, your pelvic health status and the data from the test procedure.

You will be identified by a patient ID number, and your name will not be associated with the data available for analysis.

The information collected will be treated as confidential and protected. If the data collected is used in a publication or thesis, the identity of the participant will remain anonymous.

Only the researcher will have access to the information

What will happen in the unlikely event of some form of injury occurring as a direct result of your taking part in this research study?

There is no risk of injury, unless an individual tries to force the electrode in. This should not be attempted.

There is minimal physical risk to healthy pelvically-robust individuals (both latex and non-latex gloves provided).

Potential risks include:

Physical - being unable to insert the electrode (and pushing too hard, causing some discomfort), or discomfort whilst it is inserted (uncommon, but not impossible), or discomfort after removing it. Unless the individual is a common 'thrush' sufferer (candida albicans) it is highly unlikely, and coincidental, if they were to develop thrush after this procedure. The same is true for individuals with recurrent bladder infections (part of exclusion criteria).

Emotional – some individuals suffer self-doubt if unable to self-insert the probe. They will be offered one-on-one 'counselling' by the primary investigator, explaining the implications. Some individuals might be traumatized after the testing procedure if they were vulnerable, and were *not* excluded by the stringent eligibility criteria. Most individuals will have no negative side effects, and may experience some mild euphoria (anecdotal; after having had such an unusual experience).

If you have an adverse reaction to the test procedure afterwards you will be referred to a relevant clinician, or seen personally by the PI (Corina Avni).

Will you be paid to take part in this study and are there any costs involved?

You will be remunerated at double the minimum wage of R25 per hour i.e. R50 per hour. This is due to the invasive nature of the electrode. You will be recompensed for travel at R3.50 per km, up to a total of 40kms (20km round trip), if you are not present on campus at the time and need to make a special trip.

Is there anything else that you should know or do?

You can contact Corina Avni on (removed for publication) if you have any further queries or encounter any problems.

You can contact the Health Research Ethics Committee at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by your study doctor.

You will receive a copy of this information and consent form for your own records.

Declaration by participant

By signing below, I …………………………………...………… agree to take part in a research study entitled "A description of the electromyographic activity of the pelvic floor muscles in healthy nulliparous female adults during the various weightbearing phases of the gait cycle."

I declare that:

- I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) ....…........…………….. on (*date*) …………....……….. 2016.

....

Signature of participant **Signature of witness**

Declaration by investigator

I *(name)* Corina Avni declare that:

- I explained the information in this document to …………………………………..
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did not use an interpreter.

Signed at (*place*) ....…........…………….. on (*date*) …………....……….. 2016.

....

Signature of investigator **Signature of witness**

Addendum H Australian Pelvic Floor Questionnaire

The Australian Pelvic Floor Questionnaire

Please circle your most applicable answer. Consider your experiences during the last month.

<u>Bladder function:</u>

1. How many times do you pass urine in the day?
   - 0 up to 7
   - 1 between 8 – 10
   - 2 between 11 – 15
   - 3 more than 15

2. How many times to you get up at night to pass urine?
   - 0 0 – 1
   - 1 2
   - 2 3
   - 3 more than 3 times

3. Do you wet the bed before you wake up at night?
   - 0 never
   - 1 occasionally (less than once per week)
   - 2 frequently (once or more per week)
   - 3 always (every night)

3. Do you wet the bed before you wake up at night?
   - 0 never
   - 1 occasionally (less than once per week)
   - 2 frequently (once or more per week)
   - 3 always (every night)

4. Do you need to rush or hurry to pass urine when you get the urge?
   - 0 can hold on
   - 1 occasionally have to rush (less than once a week)
   - 2 frequently have to rush (once or more per week)
   - 3 daily

5. Does urine leak when you rush or hurry to the toilet or can't get there in time?
   - 0 not at all
   - 1 occasionally (less than once per week)
   - 2 frequently (once or more per week)
   - 3 daily

6. Do you leak urine when coughing, sneezing, laughing or exercising?
   - 0 not at all
   - 1 occasionally (less than once per week)
   - 2 frequently (more than once per week)
   - 3 daily

7. Is your urinary stream (urine flow) weak, prolonged or slow?
   - 0 never
   - 1 occasionally (less than once per week)
   - 2 frequently (once or more per week)
   - 3 daily

8. Do you have a feeling of incomplete bladder emptying?
   - 0 never
   - 1 occasionally (less than once per week)
   - 2 frequently (once or more per week)
   - 3 daily

9. Do you need to strain to empty your bladder?
   - 0 never
   - 1 occasionally (less than once per week)
   - 2 frequently (once or more per week)
   - 3 daily

10. Do you have to wear pads because of urinary leakage?
   - 0 no – never
   - 1 as a precaution
   - 2 when exercising / during a cold
   - 3 daily

11. Do you limit your fluid intake to decrease urinary leakage?
   - 0 never
   - 1 before going out
   - 2 moderately
   - 3 always

12. Do you have frequent bladder infections?
   - 0 no
   - 1 1 – 3 per year
   - 2 4 – 12 per year
   - 3 more than one per month

13. Do you have pain in your bladder or urethra when you empty your bladder?
   - 0 never
   - 1 occasionally (less than once per week)
   - 2 frequently (once or more per week)
   - 3 daily

14. Does the urine leakage affect your routine activities like recreation, socializing, sleeping, shopping etc?
   - 0 not at all
   - 1 slightly
   - 2 moderately
   - 3 greatly

15. How much does your bladder problem bother you?
   - 0 not at all
   - 1 slightly
   - 2 moderately
   - 3 greatly

<u>Bowel Function:</u>

16. How often do you usually open your bowels?
   - 0 every other day or daily
   - 1 less than every 3 days
   - 2 less than once a week
   - 3 more than once a day

17. How is the consistency of your usual stool?
   - 0 soft
   - 0 firm
   - 0 hard (pebbles)
   - 2 watery
   - 1 variable

18. Do you have to strain a lot to empty your bowels?
   - 0 never
   - 1 occasionally (less than once per week)

2 frequently (once or more per week)
3 daily

19. Do you use laxatives to empty your bowels?
0 never
1 occasionally (less than once per week)
2 frequently (once or more per week)
3 daily

20. Do you feel constipated?
0 never
1 occasionally (less than once per week)
2 frequently (once or more per week)
3 daily

21. When you get wind or flatus, can you control it or does wind leak?
0 never
1 occasionally (less than once per week)
2 frequently (once or more per week)
3 daily

22. Do you get an overwhelming urgency to empty your bowels?
0 never
1 occasionally (less than once per week)
2 frequently (once or more per week)
3 daily

23 Do you leak watery stool when you don't mean to?
0 never
1 occasionally (less than once per week)
2 frequently (once or more per week)
3 daily

24 Do you leak normal stool when you don't mean to?
0 never
1 occasionally (less than once per week)
2 frequently (once or more per week)
3 daily

25 Do you have a feeling of incomplete bowel emptying?
0 never
1 occasionally (less than once per week)
2 frequently (once or more per week)
3 daily

26 Do you have to use finger pressure to help empty your bowels?
0 never
1 occasionally (less than once per week)
2 frequently (once or more per week)
3 daily

27 How much does your bowel problem bother you?
0 not at all
1 slightly
2 moderately
3 greatly

<u>Prolapse Symptoms:</u>

28 Do you have a sensation of tissue protrusion or a lump or bulging in your vagina?
0 never
1 occasionally (less than once per week)

2 frequently (once or more per week)
3 daily

29 Do you experience vaginal pressure or heaviness or a dragging?
0 never
1 occasionally (less than once per week)
2 frequently (once or more per week)
3 daily

30 Do you have to push back your prolapse in order to void?
0 never
1 occasionally (less than once per week)
2 frequently (once or more per week)
3 daily

31 Do you have to push back your prolapse in order to empty your bowels?
0 never
1 occasionally (less than once per week)
2 frequently (once or more per week)
3 daily

32 How much does your prolapse bother you?
0 not at all
1 slightly
2 moderately
3 greatly

<u>Sexual Function:</u>

33 Are you sexually active?
If you are not sexually active, please continue to answer questions 34 and 42 only
No
Less than once a week
Once or more per week
Daily or most days

34 If you are not sexually active, please tell us why (no scoring of this question)
do not have a partner
I am not interested
my partner is unable
vaginal dryness
too painful
embarrassment due to prolapse or incontinence
other reasons:____________________________

35 Do you have sufficient natural vaginal lubrication during intercourse?
0 yes
1 no

36 During intercourse vaginal sensation is:
0 normal / pleasant
1 minimal
1 painful
3 none

37 Do you feel that your vagina is too loose or lax?
0 never
1 occasionally
2 frequently
3 always

38 Do you feel that your vagina is too tight?
- 0 never
- 1 occasionally
- 2 frequently
- 3 always

39 Do you experience pain with sexual intercourse?
- 0 never
- 1 occasionally
- 2 frequently
- 3 always

40 Where does the pain during intercourse occur?
- 0 not applicable, I do not have pain
- 1 at the entrance to the vagina
- 1 deep inside, in the pelvis
- 2 both at the entrance and in the pelvis

41 Do you leak urine during sexual intercourse?
- 0 never
- 1 occasionally
- 2 frequently
- 3 always

42 How much do these sexual issues bother you?
- 0 not applicable, I do not have a problem
- 0 not at all
- 1 slightly
- 2 moderately
- 3 greatly

A validated self-administered female pelvic floor questionnaire[1]

[1] Baessler K, O'Neill SM, Maher CF, Battistutta D. A validated self-administered female pelvic floor questionnaire. International Urogynecology Journal 2010 FEB 2010;21(2):163-172.

Addendum I Australian Pelvic Floor Questionnaire Scores

Australian Pelvic Floor Questionnaire			*Sum total of all subjects for each pelvic function*
Bladder Function	1 frequency	/3	*1*
	2 nocturia	/3	*0*
	3 enuresis	/3	*0*
	4 urgency	/3	*1*
	5 urge incontinence	/3	*0*
	6 stress incontinence	/3	*3*
	7 flow rate	/3	*2*
	8 incomplete emptying	/3	*4*
	9 straining to empty	/3	*3*
	10 pads usage	/3	*1*
	11 limiting fluids	/3	*0*
	12 recurrent UTIs	/3	*0*
	13 pain on emptying	/3	*1*
	14 effects of UI	/3	*0*
	15 bothersome index	/3	*0*
Bowel Function	16 frequency	/2	*0*
	17 stool consistency	/2	*2*
	18 straining to evacuate	/3	*8*
	19 laxative use	/3	*2*
	20 constipation	/3	*7*
	21 flatus	/3	*3*
	22 urgency	/3	*4*
	23 faecal incontinence	/3	*0*
	24 faecal incontinence	/3	*0*
	25 incomplete evacuation	/3	*4*
	26 perineal splinting	/3	*4*
	27 bothersome index	/3	*6*

Prolapse Symptoms	28 bulge or lump	/3	*0*
	29 heaviness or dragging	/3	*0*
	30 manual reduction for emptying	/3	*0*
	31 manual reduction for evacuation	/3	*0*
	32 bothersome index	/3	*0*
Sexual Function	33 qualitative – frequency of activity	/0	*NA*
	34 qualitative – reason	/0	*NA*
	35 vaginal lubrication[2]	/1	** 2*
	36 sensation during intercourse	/3	*0*
	37 feeling loose	/3	*3*
	38 feeling tight	/3	*1*
	39 pain during intercourse	/3	*2*
	40 pain location during intercourse	/2	*2*
	41 leaking during intercourse	/3	*2*
	42 bothersome index	/3	*2*
Total		/116	** 70/ 928*
Average			*8,75/116*
Pain	Pelvic Pain		*0*
	Low Back Pain		*3 History of*

[2] One unit of missing data

Addendum J Feedback Form

Feedback Form

ID#:______________________________________Name (optional):__________________________

VAS – Visual Analogue Scale

0=no symptom/problem **10=maximum symptom/problem**

_______________________________***x***_____________________

0 ***10***

e.g. 6/10 moderately severe problem

Response to the test procedure:

Electrode insertion:

____

0 10

Electrode removal:

____

0 10

Any residual symptoms of:

Pain:

____

0 10

Discomfort:

____

0 10

Burning:

____

0 10

Other (please specify): _________________________

____

0 10

Addendum K Oral Podium at IUGA Scientific Meeting 2016, Cape Town, South Africa

Disclosures

- No links to industry
- No conflict of interest
- Funding
  - R2000
    - PPK Fund towards Conference attendance (IUGA 2016)

How Are The Pelvic Floor Muscles Measured During Gait And Weightbearing?
A Scoping Review Of The Literature

C. M. C. AVNI[1], R. C. JONES[2] and S. D. HANEKOM[1]

[1]Stellenbosch University, Tygerberg, South Africa
[2]University of Southampton, Southampton, UK

Background to Pelvic Function

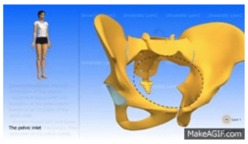
- **Dual pelvic function** (terrestrial mammals)
  1. Visceral functions
     - Bladder, bowel and sexual function
     - Childbirth (females)
  2. Musculoskeletal (MSK) function
     - Gait or locomotion
- Pelvic floor muscles (PFMs) & research
  - Consequences of and for childbirth
  - Related to visceral control

Background to Pelvic Function

- **[1] Applied an incremental force to the sacroiliac joints and used springs to simulate the tension of the PFMs**

Concluded that the PFMs
- generate backward rotation of the sacrum (both sexes)
- can increase stiffness in the pelvic ring (females)

Insights
1. biomechanical movement within the pelvic ring
2. mediated by the PFMs
3. female PFMs affect two aspects of MSK function



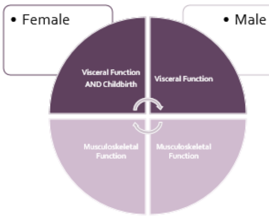
- **[2] Harvested PFMs en bloc and looked at physiological cross-sectional area, normalized fiber length, and sarcomere length**

Concluded that PFM 'design'
- is consistent with muscle sub-specialization
- shows individual muscles with differential architecture
- corresponds to specialized function

Hypotheses
1. functional roles for different PFMs (fiber length)
2. coccygeus had the shortest fibers (good stabilizer)
3. pubovisceral had the longest fibers (large excursions)

1. Pool-Goudzwaard A et al Contribution of pelvic floor muscles to stiffness of the pelvic ring. *Clin Biomech 2004 JUL 2004;19(6):564-571.*
2. Tuttle LJ et al. Architectural design of the pelvic floor is consistent with muscle functional subspecialization. *International Urogynecology Journal 2014 FEB 2014;25(2):205-212.*

Relevance in Research & Clinical Significance



- Terminology[3]
  - Voluntary & Involuntary activity
    - Contract – "Knyp/Squeeze" & Cough
    - Relax – "Let go" & Relax to pass wind
  - Bilateral PFM activity for visceral control
- Clinical Assessment and Treatment
  - PFM activity for visceral function and control
    - bilateral and simultaneous
    - PAIN (chronic pelvic pain)
  - *PFM activity during musculoskeletal function*
    - *unilateral and alternate*
    - *PAIN (chronic low back, pelvic girdle and groin, hip, adductor & hamstring pain)*

- Impact of research on Clinical Management
  - PFM function & activity in non weightbearing
  - PFM function for visceral control
  - *PFM function during musculoskeletal activity*

3. Messelink B 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):374-380.*

Relevance in Research & Clinical Significance

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Methodology

Methodological framework of Arksey and O'Malley (2005)
Additional recommendations for methodological consistency[4]

Question

"How are the PFMs measured during gait and weightbearing?"

Search

- Search Terms
  "pelvic floor muscle" OR "pelvic floor muscles" OR "pelvic floor"
  gait OR running OR walking OR jumping OR "weight bearing" OR standing
- 6 databases
  Ebsocohost (CINAHL, MEDLINE, SPORTDiscus); Pedro; PubMed; Science Direct; Scopus ; Web Of Science
- Initial search August 2014 – updated November 2015
- Research team – Primary Investigator & Second Reviewer
- Identified and reviewed separately at 3 levels – title, abstract, full text
- Inclusions – human, measurement, PFMs, weightbearing position

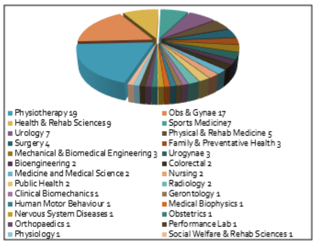
4. Levac D, Colquhoun H, O'Brien KK. Scoping studies: advancing the methodology. *Implement Sci 2010 SEP 20;5:69*

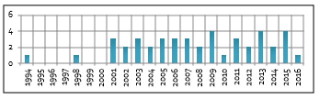
Aims and Objectives
Charting the data

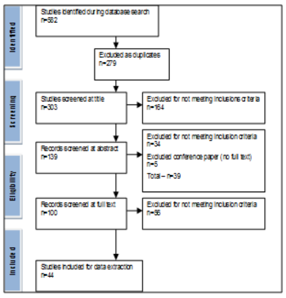
- AIM:
  - To establish the scope of the current literature
    - Volume
    - Distribution
- OBJECTIVES:
  - To extract relevant data
    - Weightbearing positions
    - Measurement modalities/tools
    - PFMs (anatomical area under investigation)
    - Population demographics (age, gender, health status, bladder status at testing)
- Extracted & entered into specifically designed spreadsheet

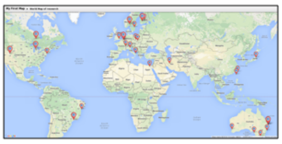
Results Scope – Volume & Distribution

44 studies in 17 countries across 25 disciplines spanning 23 years



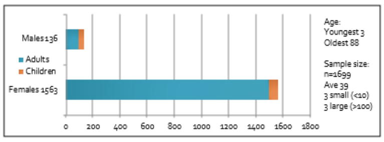






Results Data

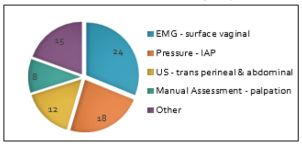
Population demographics



Pelvic floor muscles and surrogates

- PFMs – 29 studies (66%)
  - pubococcygeus 4 (9%)
  - levator ani 2 (4.5%)
  - sphincters
    - External Anal Sphincter 2 (4.5%)
    - Striated Urethral Sphincter 1 (2%)
  - puborectalis 1 (2%)
- Surrogates (15) – 21 studies (48%)
  - bladder neck, base and/or pressure
  - urethra, urethro-vesical angle, urethral pressure
  - vaginal pressure and/or walls
  - cervix, perineal descent
  - levator hiatus, levator plate
  - ano-rectal angle, rectal pressure, rectum

Measurement Modalities & Majority Test Tool



Weightbearing Positions

- Standing – 44 studies (100%)
- Gait – 5 studies (11%)
  - One EMG during single leg stepping
    - n = 5 men (healthy)
  - Two EMG during running
    - n = 10 women (healthy)
    - n = 10 women (healthy)
  - One pressure during walking & carrying
    - n = 46 women (healthy)
  - One pressure during walking, running & lifting
    - n = 57 women (healthy)
- Dynamic activities – 12 studies (27%)
  - change in ankle and/or lumbar position; ADLs; load catching; lifting; balance conditions; modified squat & on toes; arm movements; Pilates exercises

Conclusions

- The PFMs have been extensively researched
  - Less so during weightbearing / functional dynamic activities
    - UI, POP – jumping, running, lifting, coughing *in standing*
- PFMs – how much detail do we want?
  - Anterior : posterior
  - Left : right
  - Superficial : deep
- Measurement modalities
  - Reliability
  - New technology (MAPLE)
  - EMG & pressure (changing pelvic profile)
  - US & manual assessment (orientation)
- Weightbearing
  - Gravity
  - IAP
  - Movement (sports)

What is already known on this topic?
Not much
Multiple parameters of PFM activity and function differ in standing

What does this study add?
Highlights gaps in the literature

Should we change our practices based on this study?
1. *Establish normative values in functional weightbearing positions*
2. *Explore the impact of dynamic activity and weightbearing on PFM function*
3. *Describe the action and reaction of the PFMs during gait*

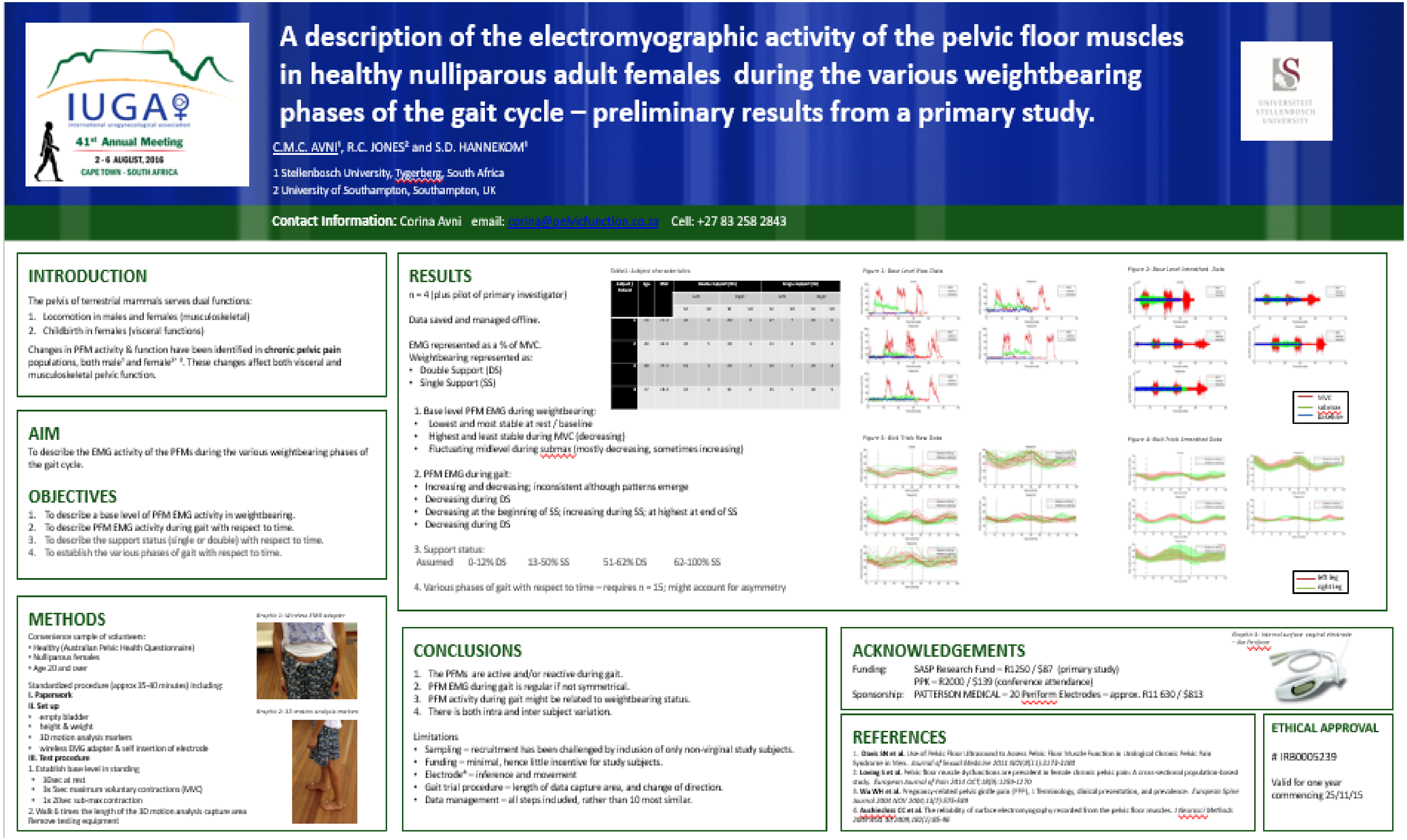
A description of EMG activity of the PFMs in healthy nulliparous female adults during the various weightbearing phases of the gait cycle…. (EP #145)

Clinical and Scientific Significance

Thank you for your attention

Any questions?

Addendum L ePoster at IUGA Scientific Meeting 2016, Cape Town, South Africa



Addendum M Budget

Consumables

Item	*Date*	*Quantity*	*Total*
Adapters	2014	4	R1440
Periform Electrodes	May 2016	20	sponsored
Tissues	2 June 2016	1 box	R20
Gloves - nitryl	2 June 2016	3 sizes of 100s	R300
Linen savers	2 June 2016	1 pack of 20s	R100
KY Jelly sachets	2 June 2016	10 @ R3	R30
Bin bags	2 June 2016	1 pack x 15	R40
Paper	2014 2015 2016	1 ream 1 ream 2 reams	R100 R100 R200
Total			**R2330**

Data capturing and processing; Calculated on 9 subjects, one subject lost due to corrupt gait data

Data	*Quantity*	*Total*
VICON	@R200 per subject	R1800
EMG	@R100 per subject	R900
Processing	Approx. R1000	R1000
Total		**R3700**

Subject reimbursement

Subject	*Payment*	*Distance*	*Paid*	*Total*
1	R50	12km x2 =24km xR3.50 =R84	3 June	R134
2	R50	22km x2 =44km xR3.50 =R154	9 June	R204
3	R50	27km x2 = 54km x R3.50 =R189	13 June	R239
4	R50	39km x2 =78km xR3.50 =R273	9 June	R323
5	R50	14km x2 =28km xR3.50 =R98	23 August	R148
6	R50	18km x2 =36km xR3.50 =R126	20 August	R176
7	R50	28km x2 =56km xR3.50 =R196	31 August	R246
8	*R50*	*25km x2 =50km xR3.50 =R175*	*23 August*	*R225 corrupt data*
9	R50	13km x2 =26km xR3.50 =R91	31 August	R141
Total				**R1836**