SURFACE ELECTROMYOGRAPHY OF THE PELVIC FLOOR MUSCULATURE: RELIABILITY AND VALIDITY OF A NOVEL ELECTRODE DESIGN

by

Nadia Keshwani

A thesis submitted to the School of Rehabilitation Therapy
In conformity with the requirements for
the degree of Master of Science

Queen’s University
Kingston, Ontario, Canada
(February, 2011)

Copyright ©Nadia Keshwani, 2011
Abstract

**Purpose**: Intravaginal probes used for recording electromyography (EMG) from the pelvic floor muscles (PFMs) likely record activity from nearby muscles (crosstalk), and move during functional tasks, causing motion artifact data contamination, threatening the validity of results obtained. This study investigated the test-retest reliability and validity of surface EMG recordings from the PFMs using a novel, theoretically superior electrode in comparison to a commercially available intravaginal probe, the Femiscan™.

**Methods**: Healthy subjects (n=20) performed tasks with each vaginal electrode in situ: i) PFM maximal voluntary contractions (MVC), ii) coughs, iii) unilateral hip adductor/external rotator contractions at 25%MVC, 50%MVC, and MVC while keeping the PFMs relaxed or maximally contracted, and iv) transversus abdominis contractions (TrA; recorded using fine-wires) at 25%MVC, 50%MVC, MVC.

**Analyses**: i) Intraclass correlation coefficients (ICC), ii) t-tests of proportions (α=0.05), iii) repeated measures ANOVAs and Tukey’s post-hoc testing (α=0.05) and iv) cross-correlation functions between peaks of transversus abdominis and PFM activity were used to determine the between-trial and between-day reliability of each vaginal electrode, a difference in prevalence of motion artifact contamination between electrodes, and the presence of crosstalk from the hip and TrA, respectively.

**Results**: Between-trial reliability of both vaginal electrodes was excellent (ICC(3,1)=0.943-0.974). Between-day reliability was less consistent (ICC(3,1)=0.788-0.924 and 0.648-0.715 for the Femiscan™ and novel electrode, respectively). No significant difference in the proportion of files contaminated with motion artifact using each electrode existed. At submaximal intensities of hip muscle contractions, the Femiscan™ recorded significantly higher EMG amplitudes compared to...
what it recorded when the hip was relaxed, whereas the novel electrode did not, indicating that the Femiscan™ recorded crosstalk from the hip musculature. Low cross-correlation coefficients (<0.90) and large time delays (≥ 0.5 milliseconds) between peaks of PFM and TrA activity indicated that neither vaginal electrode recorded crosstalk from the TrA.

**Conclusion:** The novel electrode is a promising tool to record EMG from the PFMs, as it records less crosstalk from the hip musculature than current technology while maintaining a high degree of reliability when comparing results collected within the same session; however, this electrode should not be used to compare one’s muscle activity between days.
Acknowledgements

Completing this degree has been an interesting and unique experience, one filled with immense pride and happiness at times of success, and also frustration during times of difficulty. I’ve completed this degree while accomplishing all I set out to do when I decided to continue along this path, with much help from many people. First of all, I’d like to thank my supervisor, Dr. Linda McLean, who was interested in not only guiding me through my thesis, but who also invested her time and knowledge into my personal growth, both as a researcher and health care professional. I’d also like to thank Samuel Pedlow, who was always professional, helpful, and accommodating in helping me with my data collection despite the ‘uniqueness’ of my research area. My experience would not have been as rewarding without my fellow Pelvic Floor Lab Ladies: Stephanie and Evelyne; I’ve enjoyed being part of such a close-knit laboratory. I’d also like to thank my friends, especially Safia and Amberene for their empathy, compassion, encouragement, and genuine excitement whenever I was excited. To my Mom, who knows my habits well enough to ensure that I always came back to Kingston well-stocked with food, my Dad, who listened whenever I needed to talk (even to minute details of my thesis that were probably quite boring to him), and my Brother, who always helped me out with my ‘technical difficulties’, I love you all. Finally, thank you to all of my participants who helped make this research possible. –Nadia
# Table of Contents

Abstract ............................................................................................................................................ ii
Acknowledgements ......................................................................................................................... iv
List of Figures............................................................................................................................................. ix
List of Tables.............................................................................................................................................. xi

Chapter 1 Introduction ..................................................................................................................... 1
  1.1 Role and Importance of the Pelvic Floor Muscles ................................................................. 1
  1.2 Electromyography .................................................................................................................. 1
  1.3 Electromyography and the Pelvic Floor Muscles ................................................................. 2

Chapter 2 Literature Review ............................................................................................................ 5
  2.1 The Pelvic Floor Muscles: Gross and Functional Anatomy .................................................. 5
  2.2 Electromyography: An Overview .......................................................................................... 6
    2.2.1 Electrode Material ........................................................................................................... 7
    2.2.2 Electrode Types .......................................................................................................... 7
    2.2.3 Electrode Configurations .............................................................................................. 8
  2.3 Current Approach to the Use of Electromyography in the Assessment and Treatment of the
     Pelvic Floor Muscles .................................................................................................................. 11
  2.4 Drawbacks of the Current Intravaginal Probes .................................................................... 12
    2.4.1 Probe Geometry ............................................................................................................ 12
    2.4.2 Electrode Position ......................................................................................................... 14
    2.4.3 Crosstalk ..................................................................................................................... 16
      2.4.3.1 Electrode Dimensions ............................................................................................. 16
      2.4.3.2 Electrode Configuration on the Intravaginal Probes ................................................. 17
    2.4.4 Motion Artifact ............................................................................................................. 24
    2.4.5 Reliability of EMG data Recorded from the Pelvic Floor Muscles Using Intravaginal
        Probes ..................................................................................................................................... 27
  2.5 Proposed Alternatives to Intravaginal Probes ...................................................................... 33
  2.6 Summary .............................................................................................................................. 34

Chapter 3 Methods ......................................................................................................................... 36
  3.1 Objectives .............................................................................................................................. 36
  3.2 Novel Electrode Description .................................................................................................. 37
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1.6</td>
<td>Pathway™ 6630 Vaginal/Rectal EMG Sensor</td>
<td>117</td>
</tr>
<tr>
<td>7.1.7</td>
<td>SenseRx™</td>
<td>118</td>
</tr>
<tr>
<td>7.1.8</td>
<td>EMPI Vaginal Electrode</td>
<td>119</td>
</tr>
<tr>
<td>7.1.9</td>
<td>Vaginal Sensor VS 2000™</td>
<td>119</td>
</tr>
<tr>
<td>7.1.10</td>
<td>Femelex</td>
<td>120</td>
</tr>
<tr>
<td>7.1.11</td>
<td>KS-3 Vaginal Electrode</td>
<td>120</td>
</tr>
<tr>
<td>7.1.12</td>
<td>EMG 2-Ring Vaginal Probe</td>
<td>121</td>
</tr>
<tr>
<td>7.1.13</td>
<td>VT-3 Vaginal Electrode</td>
<td>122</td>
</tr>
<tr>
<td>7.1.14</td>
<td>VS 2000 Standard Vaginal Sensor</td>
<td>123</td>
</tr>
<tr>
<td>7.1.15</td>
<td>InCare Vaginal Probe 9597</td>
<td>124</td>
</tr>
<tr>
<td>7.1.16</td>
<td>DMI Intravaginal Electrode</td>
<td>125</td>
</tr>
<tr>
<td>7.2</td>
<td>Ethics Approval</td>
<td>126</td>
</tr>
<tr>
<td>7.3</td>
<td>Recruitment Flyer</td>
<td>129</td>
</tr>
<tr>
<td>7.4</td>
<td>Queen’s Gazette Recruitment Ad</td>
<td>130</td>
</tr>
<tr>
<td>7.5</td>
<td>Letter of Information and Consent Form</td>
<td>130</td>
</tr>
<tr>
<td>7.6</td>
<td>Exercise Handout</td>
<td>135</td>
</tr>
<tr>
<td>7.7</td>
<td>Letter of Information and Consent Form</td>
<td>136</td>
</tr>
<tr>
<td>7.8</td>
<td>Abdominal and Pelvic Floor Muscle EMG Data from Subject 1</td>
<td>140</td>
</tr>
<tr>
<td>7.9</td>
<td>Abdominal and Pelvic Floor Muscle EMG Data from Subject 2</td>
<td>142</td>
</tr>
<tr>
<td>7.10</td>
<td>Abdominal and Pelvic Floor Muscle EMG Data from Subject 3</td>
<td>144</td>
</tr>
</tbody>
</table>
List of Figures

Figure 3-1: Surface head of novel electrode ................................................................. 37
Figure 3-2: Tubing to exit vagina, stopcock, syringe and connecting leads ............... 38
Figure 3-3: Testing position used for bicep maximal voluntary contractions ............... 43
Figure 3-4: Participant and investigator’s testing position during tasks involving maximal effort hip adductor contractions .................................................................................. 48
Figure 3-5: Participant and investigator’s testing position during tasks involving hip external rotator contractions ........................................................................................................... 50
Figure 4-1: Example of data recorded during the “catch a load” task using the Femiscan™ .... 66
Figure 4-2: Example of data recorded during the “catch a load” task .............................. 66
Figure 4-3: Example of data contaminated with excessive noise ........................................ 67
Figure 4-4: Example of data collected using the novel electrode during a PFM MVC ........ 67
Figure 4-5: Example of data collected during an MVC of the PFMs using the Novel electrode 69
Figure 4-6: Example of data collected during an MVC of the PFMs using the Femiscan™ .... 69
Figure 4-7: Example of data collected during an MVC of the biceps using the Delsys™ electrode ...................................................................................................................................... 70
Figure 4-8: Mean RMS amplitudes generated during the MVC task using each electrode .... 70
Figure 4-9: Example of EMG data collected from the PFMs during a cough where the data were contaminated by motion artifact .......................................................... 73
Figure 4-10: Power spectral density plot of the data in Figure 4-9 ..................................... 73
Figure 4-11: Example of data collected from the PFMs during a cough where the data are not contaminated by motion artifact ............................................................. 74
Figure 4-12: Power spectral density plot of data from Figure 4-11 .................................... 74
Figure 4-13: Average peak RMS amplitudes recorded from the right PFMs using each vaginal electrode during isolated right hip adduction tasks .................................................. 76
Figure 4-14: Average RMS amplitudes recorded from the right PFMs using each vaginal electrode during a PFM MVC and concurrent right hip adduction .............................................. 77
Figure 4-15: Average peak EMG RMS amplitudes recorded from the left PFMs using each vaginal electrode during isolated right hip adduction tasks ........................................... 79
Figure 4-16: Average peak EMG RMS amplitudes recorded from the left PFM muscles using each vaginal electrode during an isolated PFM MVC, as well as concurrent right hip adduction at increasing intensities.

Figure 4-17: Average peak EMG RMS amplitudes recorded from the right PFM muscles using each vaginal electrode during isolated right hip external rotation tasks.

Figure 4-18: Average peak EMG RMS amplitudes recorded from the right PFM muscles using each vaginal electrode during a PFM MVC and concurrent right hip external rotation.

Figure 4-19: Average peak EMG RMS amplitudes recorded from the left PFM muscles using each vaginal electrode during isolated right hip external rotation tasks.

Figure 4-20: Average peak EMG RMS amplitudes recorded from the left PFM muscles using each vaginal electrode during a PFM MVC and concurrent right hip external rotation.

Figure 4-21: EMG data recorded during a 50% MVC of the transversus abdominis muscle.
List of Tables

Table 3-1: Summary of tasks performed on each evaluation session ........................................... 55
Table 4-1: Percentage of useable files collected using each electrode ........................................... 68
Table 4-2: Between-trial reliability of EMG data recorded using each electrode. ......................... 71
Table 4-3: Mean (SD) RMS amplitudes recorded using the electrodes, on the first and second data collection sessions ............................................................................................................... 72
Table 4-4: Between day Reliability Results .................................................................................. 72
Table 4-5: Average peak correlation coefficients (r) and time lags (Δ) between PFM activity and transversus abdominis activity ........................................................................................................... 87
Chapter 1

Introduction

1.1 Role and Importance of the Pelvic Floor Muscles

The pelvic floor muscles (PFMs), located in the caudal region of the bony pelvis, primarily serve to maintain normal urinary, sexual, and ano-rectal function. These muscles are also thought to play a role in postural control (Smith et al., 2007).

Pelvic floor muscle (PFM) dysfunction may result in bowel or bladder incontinence (Devreese et al., 2004; Smith, Hosker & Warrell, 1989), pelvic organ prolapse (Dietz & Simpson, 2008; Smith, Hosker & Warrell, 1989), and/or sexual pain disorders (Reissing, Brown, Lord, Binik, & Kalifé, 2005). Studies indicate that 20 to 50 percent of the population experience some form of incontinence (difficulty controlling bowel and/or bladder function), depending on the age group studied (Nitti, 2001), and up to 18 percent of females in the general population experience sexual pain disorders (Frank, Mistretta, & Will, 2008), characterized by pain before, during, or after vaginal penetration.

The pelvic floor musculature can be divided into the superficial and deep layers. The deep PFMs are normally considered to be the muscles most affected in women with PFM dysfunction, thus, they are often the focus of physiotherapy assessment and treatment in patients with incontinence or sexual pain disorders.

1.2 Electromyography

Electromyography (EMG) is a tool used to record muscle activity. The trigger for a voluntary muscle contraction is an electrical signal originating from the brain. Once the electrical signal reaches the spinal cord, it is transmitted by the alpha motor neuron and arrives at the
junction between the neuron and its innervated muscle fibers. There is a further transmission of this electrical signal at the neuromuscular junction (synapse) which allows electrical impulses (action potentials) to be transmitted along the muscle fibers innervated by that alpha motor neuron. The alpha motor neuron and the muscle fibers it innervates are referred to as a motor unit, and therefore the summation of action potentials transmitted along the muscle fibers belonging to a motor unit is termed a motor unit potential. A motor unit potential causes cellular processes which shorten the sarcomeres within each muscle fiber, thus producing a contraction of that motor unit. An EMG signal is the recording of all motor unit potentials located within the vicinity of the EMG recording electrodes (De Luca, 1978). These electrodes can either be placed inside the muscle of interest (intramuscular electrodes; for example, fine wire or needle electrodes), or on the skin overlying the muscle (surface electrodes). Depending on the electrode type, the amplitude of the EMG signal may reflect the general state of activation in a muscle, with increases in force output generally resulting in higher EMG activation amplitudes. Several recording parameters must be considered when recording and interpreting EMG data, and standards for recording EMG data have been well established in the literature (The SENIAM group, 2010). In terms of using surface electrodes for such measures, electrode material, size, shape, configuration and location are all important factors.

1.3 Electromyography and the Pelvic Floor Muscles

Surface EMG is considered to be an objective method of evaluating the gross neuromuscular function of the PFM s in the research realm (Bradley, Smith, & Kreder, 2008). It is also frequently used in the clinical sphere for treatment purposes, in the form of biofeedback (Koh, Young, Young, & Solomon, 2008; Rosenbaum, 2005).
Since the PFMs are found adjacent to the vaginal walls, surface electrodes positioned internally, against the lateral vaginal walls are able to record activity from the adjacent PFMs. The current technology used for recording surface EMG from the PFMs consists of electrodes mounted onto the surface of a probe, which is then inserted into the vagina (Bo & Sherburn, 2005). The electrodes are positioned on the probe’s surface such that ideally, they should be located at the level of the deep PFMs when inserted into the vaginal canal.

Although these intravaginal probe designs are currently used for recording surface EMG from the PFMs, major drawbacks exist concerning their design. These drawbacks include flawed probe geometry, electrode position relative to the anatomic location of the PFMs, electrode configuration, and questionable reliability.

Many commercially available intravaginal probes are large in diameter, which may affect patient comfort upon use. These probes may also put a stretch on the adjacent PFMs when in situ. For assessment purposes, it is undesirable to put a stretch on the PFMs (i.e. lengthen them), as this may change their contractile properties (Dumoulin, Gravel, Bourbonnais, Lemieux, & Morin, 2004), and thus may change the amount of muscle activity generated compared to that which would be generated under normal physiological conditions without the probe in place.

Concerning electrode position, the electrodes are fixed onto the probe’s surface, thus, their position cannot be varied depending on each person’s anthropometry. As such, when recording EMG using these probes, the electrodes may not be appropriately placed at the level of the deep PFMs in all women (Voorham-van der Zalm et al., 2006).

Electrode configuration also tends to be inappropriate when using most intravaginal probes, as the configurations often treat the PFMs on the right side of the pelvis and those on the left side of the pelvis as the same muscle, despite the fact that they have separate origins and
insertions, and distinct nerve supplies. This configuration also increases the likelihood of recording unwanted EMG signals from nearby muscles, including the hip adductors, external rotators, lower abdominals, and gluteal muscles, rather than solely recording EMG from the PFMs; this unwanted activity compromises the validity of EMG results obtained from the PFMs.

Lastly, mixed results regarding between-day reliability have been reported in the literature when using intravaginal probes to record EMG from the PFMs (Auchincloss & McLean, 2009b; Grape, Dedering, & Jonasson, 2009). These results, combined with the challenges associated with the internal nature of recording EMG from the PFMs, have given rise to the belief that PFM EMG is less reliable than recording EMG from more easily accessible skeletal muscles (L. McLean, personal communication, 2010).

Despite the major drawbacks of the intravaginal probe design, an optimal design of surface electrode for recording EMG from the PFMs is not commercially available. Dr. L. McLean and Mr. R. Young have recently designed a theoretically superior electrode for recording EMG from the PFMs, however this electrode has not been evaluated against the current technology.

Thus, the main purpose of this study was to investigate the test-retest reliability and validity of a novel, theoretically superior, surface electrode for recording EMG from the PFMs and to compare it to a commonly available intravaginal probe, the Femiscan™, in healthy women. A secondary purpose was to compare the reliability of EMG results recorded from the PFMs to the reliability obtained when recording EMG from a more easily accessible skeletal muscle.
Chapter 2

Literature Review

2.1 The Pelvic Floor Muscles: Gross and Functional Anatomy

The pelvic floor musculature can be divided into the superficial and deep layers. The muscles of interest in this study are those that form part of the deep layer, as these muscles are normally considered to be most affected in women with PFM dysfunction, and therefore they are often the focus of PFM assessment and treatment. The deep muscles of the pelvic floor, located approximately 2.5 cm deep to the superficial perineal area (Bo, Kvarstein, Hagen, & Larsen, 1990) consist of the levator ani group and the bilateral ischiococcygeus muscles (Fritsch, 2006). The levator ani group consists of the pubococcygeus muscles, the iliococcygeus muscles, and the puborectalis muscles (Fritsch, 2006). The pubococcygeus muscles originate on either side of the superior ramus of the pubis, and insert onto the coccyx (Schunke, Schulte, Ross, Schumacher, & Lamperti, 2006). The iliococcygeus muscles originate just posterior to the pubococcygeus muscles, however, they do not have a direct bony origin. Instead, they arise from a reinforced fascial band, the tendinous arch of the obturator internus fascia (Schunke et al., 2006) on each side of the pelvis. They too insert onto the coccyx (Schunke et al., 2006). The final portions of the levator ani group, the puborectalis muscles, have their bony origin below the pubococcygeus muscles, on the inner surface of superior ramus of the pubis (Schunke et al., 2006). They insert onto the anococcygeal ligament (Schunke et al., 2006). The ischiococcygeus muscles arise from the ischial spine and supraspinous ligaments bilaterally, and insert onto the lateral aspects of the coccygeal vertebra (Fritsch, 2006).
It is generally thought that the PFMs contract bilaterally, as a unit, as the neurons innervating each side work in harmony (Enck & Vodusek, 2006). As such, it is not possible to activate the right and left sides of the PFMs separately (Enck & Vodusek, 2006). It is important to note, however, that the PFMs on one side of the pelvis have separate and distinct origins, insertions, and neurovascular supplies compared to those located on the other side of the pelvis. As such, although the PFMs contract as a functional unit, it is plausible that asymmetries in muscle morphology and muscle activation may exist.

Many studies have reported side to side differences in either PFM thickness, seen through ultrasound imaging or magnetic resonance imaging (Aukee, Usenius, & Kirkinen, 2004; Bernstein, 1997; Fielding et al., 2000), or in PFM activity (Auchincloss & McLean, 2009b; Aukee et al., 2004). Based on these asymmetries and the distinct anatomy of the right and left sides of the PFMs, it is inappropriate to regard the PFMs on the right and left sides of the pelvis as one general muscle. Instead, each side of the PFMs should be evaluated separately.

### 2.2 Electromyography: An Overview

The trigger for a muscle contraction is an electrical signal (action potential) originating from the motor cortex of the brain. Once the action potential reaches the spinal cord, it synapses with an alpha motor neuron and continues to travel along this neuron until it arrives at the junction it forms with its innervated muscle fibers. The signal synapses again such that muscle fiber action potentials are produced on all muscle fibers innervated by the particular alpha motor neuron. These muscle fiber action potentials depolarize the sarcolemma, resulting in cellular processes that eventually cause a shortening of the contractile units (sarcomeres) within the involved muscle fibers. Each muscle fiber produces twitch force as it shortens, and the summation of muscle twitches from all active motor units produces a muscle contraction. An
EMG signal is the recording of all motor unit potentials located within the vicinity of the EMG electrodes (De Luca, 1978).

Different types of EMG electrodes exist (surface or intramuscular), and may be configured in different ways (monopolar or differential). Electrode types and configurations are further described below.

2.2.1 Electrode Material

Silver-silver chloride (Ag/AgCl) is typically recommended for electrode construction due to its stable nature (The SENIAM group, 2010; Webster, 1998). Gold electrodes may also be used, as they are highly conductive while remaining relatively stable (The SENIAM group, 2010; Webster, 1998). The value of using Ag/AgCl recessed electrodes is described in Section 2.4.4. With reference to PFM EMG, however, stainless steel electrodes are typically found on intravaginal probes.

2.2.2 Electrode Types

Two main types of electrodes are used for EMG recordings: surface electrodes and intramuscular (fine wire or needle) electrodes. Surface electrodes are placed on the skin surface overlying the muscle of interest; whereas fine wire or needle electrodes are placed within the muscle itself. Choice of electrode type depends on the purpose of the EMG recordings. For example, surface electrodes are preferred when one is interested in evaluating the gross activity of a superficial muscle (Basmajian, 1978). The advantages of these types of electrodes are that they are easy-to-use and non-invasive; however, these electrodes are generally only useful for recording the activity from large muscles close to the skin surface (Basmajian, 1978).
On the other hand, fine wire electrodes are preferred when one would like to record the activity of deeper muscles, whose activity would be more difficult to detect in isolation using surface electrodes. Fine wire electrodes are inserted into the target muscle using a needle cannula (hollow tube) which pierces the skin and enters the muscle itself. The fine wires are located within the cannula, and when they enter the muscle, they hook onto the muscle tissue. Thus, when the needle is removed, the wires remain in place. A drawback inherent in the use of fine wire electrodes is that their insertion is invasive and may cause discomfort. Furthermore, there is a risk of infection or hemotoma if a blood vessel is accidentally pierced.

Needle electrodes are used when one wishes to examine the recruitment, size, shape, and stability of firing of individual motor unit potentials (Stålberg, 2003). It is especially useful in the neurological examination of neurogenic or myopathic muscles. However, discomfort may be associated with needle EMG, as the electrode is located at the needle tip, and remains inside the muscle while recording EMG.

2.2.3 Electrode Configurations

Using modern instrumentation systems, surface electrodes can be configured in one of two ways: monopolar or differential. In a monopolar configuration, one (active) electrode is positioned over the muscle of interest. The signal obtained from the active electrode is compared to the signal obtained from a reference electrode, normally placed over an electrically neutral area of the body (i.e. bony prominence). All signals common to both the active and reference electrode, such as the signals generated by cardiac activity or the electrical activity in the environment, are eliminated from the resultant EMG signal (See Figure 2-1). The advantage of using this configuration is that it tends to record large amplitude signals. The disadvantage of this electrode configuration is that activity from muscles other than the muscle of interest can be
recorded, and represented in the resultant EMG signal (See Figure 2-1). Detecting and recording signals that originate from nearby muscles rather than the solely from the muscle of interest is known as crosstalk. Crosstalk is even more likely to occur when the electrodes are large in size or when the active electrode and reference electrode are spaced far apart, as both factors increase the ability to record activity from muscles farther away (Basmajian, 1978).

Figure 2-1: Monopolar Electrode Configuration. \( m_1 \) represents EMG activity recorded from the muscle of interest, \( m_2 \) represents EMG activity from a nearby muscle, and \( n \) represents noise in the environment. Note: muscle activity from a nearby muscle (\( m_2 \)) appears in the resultant EMG signal, resulting in crosstalk.

In order to decrease the likelihood of recording crosstalk, differential electrode configurations are often recommended for surface EMG recordings (The SENIAM group, 2010). In a single differential configuration, two active electrodes (positive and negative) are positioned in line, over the muscle of interest, and a separate reference electrode is placed over an electrically neutral area of the body. The signal from one of the active electrodes placed over the muscle of interest is subtracted from the signal recorded by the other active electrode located over the same muscle. In this configuration, the reference electrode removes all signals common to
both the positive and negative electrodes (See Figure 2-2). High frequency signals originating from muscles farther away from the electrodes attenuate over the distance travelled (Basmajian, 1978). As a result, by the time an electrical signal from a nearby muscle reaches the differential EMG electrodes, the signal looks similar to both electrodes (Basmajian, 1978). Thus, it is eliminated from the differential EMG signal, making crosstalk from nearby muscles less likely to be an issue. Signals from the muscle of interest lying just beneath the two active electrodes will not be eliminated from the resultant EMG signal, as each of the two active electrodes will record the signal at different points in time as the action potentials propagate down the muscle fiber (Basmajian, 1978).

![Figure 2-2: Differential Electrode Configuration.](image)

Figure 2-2: Differential Electrode Configuration. \( m_1 \) (at \( t_1 \)) is the target muscle activity recorded by the first active electrode, and \( m_1 \) (at \( t_2 \)) is the target muscle activity recorded by the second active electrode, \( m_2 \) represents the muscle activity from a nearby muscle, and \( n \) represents noise from the environment. Noise from the environment, as well as activity from nearby muscles looks similar to both active electrodes because they originate from farther away. The noise from the environment and activity from nearby muscles are subtracted out of the final EMG signal.
A further step is a double differential electrode configuration which may be used to further decrease the likelihood of recording crosstalk. In this configuration, three active electrodes (E1, E2, and E3) are positioned in line, over the muscle of interest. Two separate differential signals \( E_{(1,2)} \) and \( E_{(2,3)} \) are obtained from pairs of electrodes (i.e. E1 - E2, and E2 – E3). A final differential EMG signal is then obtained using the previous two differential signals (i.e. \( E_{(1,2)} - E_{(2,3)} \)), thus, the EMG signal output has undergone two stages of differentiation.

### 2.3 Current Approach to the Use of Electromyography in the Assessment and Treatment of the Pelvic Floor Muscles

EMG is considered to be an objective method of evaluating the gross neuromuscular function of the PFMs in the research realm (Bradley, Smith, & Kreder, 2008). It is also frequently used in the clinical sphere for treatment purposes, in the form of biofeedback (Koh, Young, Young, & Solomon, 2008; Rosenbaum, 2005).

Fine wire, needle, and surface electrodes may all be used to record activity from the PFMs; however, the latter are often the preferred method as they are the least invasive of all the electrode types, are easy to use, and record global muscle activation. Since the PFMs are found adjacent to the vaginal walls, surface electrodes positioned inside the vaginal canal against the lateral vaginal walls are able to record activity from the PFMs. One challenge that arises when using surface EMG to record activity from the PFMs is the moist environment of the vaginal canal. As a result of this environment, typical adhesive surface electrodes used in EMG recordings from other skeletal muscles are not appropriate to use on the PFMs, as these electrodes do not adhere to the vaginal walls. Instead, electrodes mounted onto the surface of a probe, which can be then inserted into the vagina, are typically used when recording surface EMG from the PFMs (Bo & Sherburn, 2005). The electrodes are positioned on the probe’s surface such that
ideally, they should be located at the level of the deep PFMs when inserted into the vaginal canal. Because of the inability to use adhesives, recessed electrodes are not used for recording EMG from the PFMs.

Although this design is a viable alternative to the recessed, adhesive surface electrodes typically used to record EMG data from other skeletal muscles, drawbacks exist.

2.4 **Drawbacks of the Current Intravaginal Probes**

The main drawbacks of using intravaginal probes to record EMG from the PFMs include flawed probe geometry, fixed electrode position, inappropriate electrode size and configuration and the tendency of the probes to move during functional tasks.

2.4.1 **Probe Geometry**

The first two issues pertain to the dimensions of the probe onto which the electrodes are mounted. At the level of the deep PFMs, the diameter of the vaginal canal is 2.79cm ± 0.55cm (Barnhart et al., 2006). The diameters of the Femiscan™, Periform™, and Veriprobe™, three commonly used intravaginal probes (See Appendix 7.1) are 2.5cm, 3.4cm, and 2.6cm, respectively. Thus, insertion of any of these probes will likely stretch the vaginal tissue and the underlying PFMs in some women and not in others, depending on their vaginal morphology. Voorham-Van Der Zalm et al. (2006) demonstrated this displacement of vaginal tissue and underlying musculature when both the Periform™ and Veriprobe™ were used, revealed through magnetic resonance and ultrasound imaging. The Femiscan™ was not tested; however, based on its dimensions, it is also likely to stretch the vaginal tissue and PFMs, but to a lesser extent than the other probes considering its smaller diameter.

It is undesirable to stretch the vaginal walls, and thus, the underlying PFMs when recording muscle activity, as the PFMs, like all skeletal muscles, have contractile characteristics
that change depending on muscle length (Gordon, Huxley, & Julian, 1966). Putting a stretch on
the PFMs (i.e. lengthening them) may change the contractile properties of the muscles, and thus
may change the amount of muscle activity generated compared to that which would be generated
under normal physiological conditions without the probe in place. In a study by Dumoulin,
Gravel, Bourbonnais, Lemieux, and Morin (2004), women were able to produce higher peak
force values during a voluntary PFM contraction as the diameter of the vagina was increased
using an instrumented speculum (p < 0.0001). The higher peak forces may have been due to
changes in the active or passive components involved in force generation (Banus & Zetlin, 1938).
Until it is confirmed that this change in force generating capacity was entirely due to changes in
the passive forces in the tissues, it is preferable to record surface EMG from the PFMs in their
normal physiological state, which is not possible using the currently available intravaginal probe
designs.

Another issue concerning probe geometry is comfort. The smallest diameter within the
vagina is found just inside of the vaginal introitus or entrance (Barnhart et al., 2006). At this
level, the width of the vagina is approximately 2.61 cm ± 0.44 cm (Barnhart et al., 2006), the
specific width being dependant on each woman’s anatomy. When inserting these probes, the
largest portion of the probe must first pass through the vaginal introitus. Insertion of the
Periform™ in particular, with its large diameter, is reported to be uncomfortable for many
(particularly nulliparous) women (Brown, 2007). In our laboratory, some women have been
physically unable to insert the Periform™ due to its large dimensions. Even the Femiscan™ and
Veriprobe™, with their smaller diameters, are likely to be uncomfortable for some women,
especially those with pelvic or sexual pain disorders. Sexual pain disorders are characterized by
pain before, during, or after vaginal penetration. Thus, the insertion of the intravaginal probe to
record surface EMG for assessment or treatment purposes may result in discomfort in women with such conditions. The Femiscan™, in particular, can remain uncomfortable especially when women change positions as, unlike the other probes, it does not taper at the level of the introitus (Brown, 2007).

2.4.2 Electrode Position

As mentioned in Section 2.3, in commercially available probes, electrodes are fixed onto the probe’s surface. Although the electrodes on each probe are positioned such that ideally, they should be at the level of the PFMs when inserted into the vagina, this may not be the case. For example, the puborectalis muscle is one of the most important PFMs in the maintenance of fecal continence, thus, it can be a focus of both assessment and treatment in fecal incontinence. Voorham-van der Zalm et al. (2006) investigated the placement of electrodes on the Periform™ and VeriProbe™ relative to the puborectalis muscle when inserted correctly into the vagina. Even when inserted correctly, the detection surfaces on the probes were not positioned adjacent to the puborectalis muscle, despite their large detection surfaces. The electrodes on the Periform™ were positioned 3 cm cranial to the puborectalis muscle when the probe was properly inserted into the vagina. The position of the electrodes on the Femiscan™ probe relative to the PFMs was not evaluated.

Incorrect positioning of the electrodes relative to the PFMs is even more likely when circumferential as opposed to longitudinal electrodes are used. Electrodes placed longitudinally run parallel to the long axis of the probe. Examples of probes that feature longitudinal electrodes include the Femiscan™, T6050, Periform™, VeriProbe™, Pathway™ 6330, Pathway™ 6630, SenseRx™, VS 2000™ Standard Instruments Probe, and the Femelex (See Appendix 7.1). Electrodes placed circumferentially are ring-shaped, following the diameter of the probe.
Although many probes feature circumferential electrodes (EMPI Vaginal Probes, KS-3 Vaginal Electrode, EMG 2-Ring vaginal electrode, VT-3 Vaginal Electrode, and VS 2000 Haynl Vaginal Sensor; See Appendix 7.1), positioning electrodes in this way is undesirable for recording EMG activity because electrodes in a ring are much more dependent on the electrode being at the level of the PFMs compared to longitudinal electrodes. Vaginal geometry, and thus the position of the PFMs within the vagina, varies depending on a women’s specific anatomy (Barnhart et al., 2006). As such, circumferential electrodes, usually less than 1 cm wide, may be positioned at the level of PFMs in one woman but may be positioned inappropriately in another woman. Incorrect positioning of circumferential electrodes relative to the PFMs is even more likely to be a problem in parous women, as vaginal delivery may damage the PFMs and cause partial or complete tears (avulsion) of these muscles (Dietz & Lanzarone, 2005). Thus, it is possible that the circumferential electrodes may be undesirably positioned at the level of the avulsed segment of the PFMs.

This problem regarding the incorrect positioning of electrodes relative to the PFMs is further compounded by the fact that the position of the PFMs changes during a PFM contraction. During a PFM contraction, the PFMs move cranially and ventrally (Aukeye et al., 2004; Hugosson, 1991). Thus, circumferential electrodes or small longitudinal electrodes may be positioned at the level of the PFMs at rest, however, may not be positioned at the appropriate level during a contraction.

Another drawback of circumferential electrodes is that they will detect all recordable signals from muscles near the anterior, posterior, and lateral walls of the vagina. Thus, the recorded EMG signal is a nonspecific representation of the general muscle activity around the vagina. This is described further below.
2.4.3 Crosstalk

When recording surface EMG using intravaginal probes, recording crosstalk from nearby muscles is highly probable, due to the large size of electrodes (Basmajian, 1978), as well as the inappropriate way in which these electrodes are configured.

2.4.3.1 Electrode Dimensions

Surface electrodes should be large enough to be able to record a reasonable amount of activity from the target muscle, but small enough to avoid crosstalk from other muscles (The SENIAM group, 2010). In accordance with these guidelines, De Luca (1997) recommends small surface electrodes, with lengths of 1 cm and widths of 0.1 to 0.2 cm in order to avoid recording crosstalk. Instead, the electrodes featured on the surfaces of the intravaginal probes tend to be oversized. For example, the Veriprobe™ features the largest electrodes, each of its two electrodes being 2.0 cm wide and 3.5 cm in length, and having a surface area of 7.0 cm². The Femiscan™, which features some of the smallest electrode surface areas compared to other intravaginal probes, employs electrodes that are 0.3 cm wide and 5.8 cm in length. Thus, even one of the “best” electrode designs currently available, the Femiscan™, does not follow the recommended guidelines for electrode size. The electrodes on intravaginal probes seem even more oversized when one considers the dimensions of the PFMs. Although no studies have quantitatively assessed PFM width, it is apparent when looking at dissections that PFM width is less than 1 cm and thus is much smaller than the length of electrodes typically found on intravaginal probes (L. McLean, personal communication, 2010). As such, the electrodes tend to surpass the entire width of the PFMs.

The tendency for commercial probe designs to feature large electrodes likely occurs for two reasons. First, larger electrodes are more likely to be placed at the level of the PFMs in most
women, compared to smaller electrodes. Second, intravaginal probes that feature large electrodes can be marketed for electrical stimulation use in addition to EMG biofeedback, as larger electrodes distribute an electrical current over a larger surface area and thus are more comfortable upon use compared to smaller electrodes (Alon, 1985). On the other hand, manufacturers state that probes that feature small electrodes are recommended for biofeedback only (The Prometheus Group, personal communication, 2010). Although probes that feature large electrodes are considered to be superior in that they are ‘dual purpose’, they are associated with an increase in likelihood of recording crosstalk (Basmajian, 1978).

### 2.4.3.2 Electrode Configuration on the Intravaginal Probes

Although a differential electrode configuration is preferred, (See Section 2.2.2; The SENIAM group, 2010) none of the commercially available intravaginal probes employ true differential electrode configurations. In order to obtain a true differential configuration, two active electrodes must be positioned over the same PFM. Instead, intravaginal probes almost exclusively have electrodes positioned such that one active electrode records the signal from one side of the PFMs, and the other active electrode picks up the signal from the PFMs on the opposite side of the pelvis. If a differential amplifier is used, the signals recorded from one side of the PFMs are subtracted from those recorded on the other side. This ‘faux’ differential configuration is inappropriate for two reasons. First, this configuration does not allow one to record EMG from the right and left PFMs separately, although differences in muscle activity from side to side are likely (See Section 2.1). Second, the two active electrodes are located on opposite sides of the pelvis. This spacing increases the likelihood that signals originating from nearby muscles (Basmajian, 1978), especially during unilateral contractions, will not look similar.
to both active electrodes. Thus, signals from nearby muscles may contaminate the resultant EMG signal with crosstalk, threatening the validity of results obtained.

It is possible to re-wire probes that feature a ‘faux’ differential electrode configuration to a true differential configuration if the probe has two electrodes on each side of the probe’s surface. This re-wiring has been reported in research articles (Auchincloss & McLean, 2009b; Grape et al., 2009). Unfortunately, with the exception of the Femiscan™, commercially available intravaginal probes tend to feature only one electrode on each side of the probe, thus, re-wiring it to a true differential configuration is not possible.

It is also possible to re-wire electrodes that are arranged in an inappropriate ‘faux’ differential configuration to a monopolar configuration (Auchincloss & McLean, 2009b). The advantage of doing so is that one will be able to record activity from the right and left PFMs separately instead of treating the right and left PFMs as the same muscle; however, employing such a monopolar configuration increases the likelihood of crosstalk (See Section 2.2.3).

2.4.3.3 Major Sources of Crosstalk When Recording EMG from the PFMs

The key muscle groups that are closest to the PFMs, and thus pose the highest threat of crosstalk are the lower abdominals, hip adductors, hip extensors, and hip external rotators. The transversus abdominis muscle fibres originate from the iliac crest, the inguinal ligament, and the cartilage of the lower six ribs, and insert onto the pubis (Schunke et al., 2006). As mentioned in Section 2.1, both the pubococcygeus and puborectalis muscles originate at the pubis, thus, the transversus abdominis muscle is in close proximity to these PFMs and is a possible source of crosstalk.

The main hip adductors are adductor longus, adductor brevis, and adductor magnus. The adductor longus muscle originates at the superior pubic ramus and the anterior pubic symphysis.
(Schunke et al., 2006), near to the pubococcygeus and puborectalis muscles. Adductor brevis originates from the inferior pubic ramus (Schunke et al., 2006). Adductor magnus has multiple origins, including the inferior pubic ramus as well as the ischial ramus and ischial tuberosity (Schunke et al., 2006). Its origin at the pubic ramus causes adductor magnus to be in the vicinity of the pubococcygeus and puborectalis muscles, whereas the fibres that originate at the ischial tuberosity are near the ischiococcygeus muscles. Thus, taken as a group, the hip adductors provide a logical source of crosstalk for EMG recordings from the PFMs.

The primary extensors of the hip are the gluteus maximus and the hamstrings, including biceps femoris, semimembranosus, and semitendinosus. Gluteus maximus has multiple origins, including the posterior iliac crest, the dorsal surface of the lower sacrum, the lateral aspect of the coccyx, and the sacrotuberous ligament (DeFranca & Levine, 1996). The hamstrings originate from the ischial tuberosity (DeFranca & Levine, 1996). Thus, the hip extensors are in the vicinity of the ischiococcygeus muscles, and may cause crosstalk when evaluating these PFMs.

The hip external rotators are the most likely source of crosstalk due to their anatomical features. Obturator internus originates on the internal surface of the obturator membrane covering the obturator canal, and the ischiopubic ramus (Schunke et al., 2006). The iliococcygeus muscles originate from the fascia of the obturator internus muscles. Because the obturator internus muscle actually provides a site of muscle attachment for one of the PFMs, it poses the most serious threat of crosstalk when recording EMG from the PFMs.

2.4.3.4 Challenges: Crosstalk versus Co-activation

The detection of crosstalk during EMG recordings from the PFMs has been very poorly and sparsely investigated, in part due to the difficulty encountered when attempting to differentiate between crosstalk and co-activation of the PFMs. Both the transversus abdominis
and obturator internus muscles are thought to perform synergistic actions with the PFMs (Spitznagle, 2006).

It has been reported in the literature that contraction of the transversus abdominis muscle facilitates a contraction of the PFMs (Junginger, Baessler, Sapsford, & Hodges, 2008). Sapsford and Hodges (2001) found that a maximal transversus abdominis contraction produced a signal at the PFMs equivalent to instructing participants to maximally contract their PFMs. However, they used the Periform™ intravaginal probe, which features large detection surfaces (see Appendix 7.1.3). This may have resulted in crosstalk being recorded and subsequently interpreted as a synergy.

Because the obturator internus muscles and PFMs are physically linked by the obturator internus fascia, a contraction of the obturator internus muscle may pull on the obturator fascia, and the PFMs to which the fascia are attached. This may stimulate a contraction of the deep PFMs by providing them with a stretch stimulus. This concept of creating a physiological stretch on the PFMs via an obturator internus contraction, thereby facilitating a PFM contraction, has not been investigated as of yet (Spitznagle, 2006), likely because of the inherent difficulty of inserting fine wire electrodes into the obturator internus.

A method referred to as selective muscle activation using electrical stimulation may be used to differentiate between crosstalk and co-activation (Deluca & Merletti, 1988). Using this method, one would stimulate the nerve innervating the nearby muscle thought to be causing crosstalk, either by stimulating peripherally or at the level of the nerve root, and recording the resultant surface EMG from the target muscle. To use this approach to determine whether crosstalk was interfering with EMG recordings from the PFMs, one would stimulate the nerves or roots innervating the obturator internus or transversus abdominis and record surface EMG from
the PFMs while participants kept their PFMs relaxed. One challenge that arises in attempting to selectively activate the obturator internus is that the obturator internus and PFMs are both innervated by overlapping portions of the sacral plexus (Aung, Sakamoto, Akita, & Sato, 2001; Grigorescu, 2008), thus, one may not be able to selectively activate the obturator internus without also activating a portion of the PFMs when stimulating at the level of the nerve roots. Stimulating the nerve innervating the obturator internus peripherally is also problematic, due to restricted accessibility to the muscle and its motor points. The transversus abdominis, on the other hand, may be more easily selectively activated, both at the nerve root level, and peripheral nerve level. It is innervated by portions of the lumbar plexus and thus selective muscle activation through stimulation of the nerve roots is theoretically possible. Furthermore, the transversus abdominis’ anatomical location makes it easier to stimulate its innervating nerve peripherally, compared to stimulating the obturator internus peripherally.

Although selective muscle activation using electrical stimulation is the only method available for differentiating between crosstalk and co-activation, “it is not clear whether the results of electrical stimulation studies may be extended to voluntary contractions, due to the synchronous activation of motor units during electrical stimulation and the activation of different motor unit populations during voluntary and electrically elicited contractions” (Lowery, Stoykov, & Kuiken, 2003). Thus, results obtained using the selective muscle activation method may not be indicative of the presence or amount of crosstalk recorded during a voluntary contraction of a neighbouring muscle.

2.4.3.5 Evidence: Crosstalk at the Pelvic Floor Muscles

Thus far, the majority of studies investigating the presence of crosstalk when using an intravaginal probe to record surface EMG from the PFMs have used small sample sizes of one or
two subjects, and have only investigated low intensity contractions of neighboring muscles (Smith, Coppieters, & Hodges, 2007; Hodges, Sapsford, & Pengel, 2007; Sapsford & Hodges, 2001). In these cases, no crosstalk was detected from the internal oblique abdominals, rectus femoris, hip adductors, gluteus maximus, or medial hamstrings when recording EMG from the PFMs. It is important to note that although obturator internus is the most likely source of crosstalk, the external rotators were not included in the above studies.

Madill & McLean (2004) investigated the effect of gluteal, hip adductor, hip external rotator, rectus abdominus, and transversus abdominis contractions on an EMG signal recorded at the PFMs, using the Femiscan™, and on intravaginal pressure, measured simultaneously, in eight women. A maximal PFM contraction was held, while PFM EMG and vaginal wall pressure were recorded simultaneously, and then neighboring muscle contractions were added to the maximal PFM contraction. Crosstalk was said to likely have occurred if there was an increase in EMG signal amplitude at the PFMs when contracting the PFMs and neighboring muscles simultaneously compared to the signal obtained during an isolated PFM contraction, without a concurrent increase in intravaginal pressure. In two of the eight women, crosstalk from the hip external rotators and the abdominals was concluded to be an issue.

Auchincloss & McLean (2009a) also investigated the effects of hip adduction, internal rotation, and external rotation on the signal recorded by the Femiscan™ and Periform™ in nine subjects. Data were collected when the PFMs and hip musculature were at rest, as well as during a maximal contraction of the hip musculature. Fine wire EMG from the PFMs and surface EMG using an intravaginal probe were recorded simultaneously. Crosstalk was said to be likely to have occurred if EMG amplitudes recorded using the intravaginal probes increased compared to values recorded when the hip muscles remained relaxed, without concurrent increases in PFM activity
recorded using fine wires. EMG activation was significantly greater than rest during hip adduction and external rotation when the Femiscan™ was used, and during all hip tasks when the Periform™ was used. However, EMG activation was only greater than rest during the external rotation task when recorded with the fine wire electrodes, suggesting that crosstalk was being recorded from the hip adductors using the Femiscan™ and from the hip adductors and rotators using the Periform™.

van der Velde & Everaerd (1999) also investigated the effect of surrounding muscle group contractions on surface EMG recordings of the PFMs using an acrylic plug with three electrodes embedded lengthwise on its surface (model name or manufacturer not provided) in 67 women with vaginismus, a sexual pain disorder, and 43 control subjects. Women were asked to first contract only their PFMs. After data were collected for this trial, they were then instructed to contract their abdominals or hip adductor muscles in conjunction with their PFMs. The amplitude of the recorded EMG signal during the PFM contraction increased with the added abdominal and hip adductor muscle contraction compared to an isolated PFM contraction, suggesting that crosstalk was being recorded from these neighboring muscles. It should be noted that although subjects were likely instructed to contract their PFMs maximally, this was not specified in the article. In this case, it is possible that the authors were not recording crosstalk but that subjects tended to perform larger PFM contractions due to facilitation induced by neighboring muscle contractions.

Peschers, Gingelmaier, Jundt, Leib, & Dimpfl (2001) also investigated the effect of neighboring muscle contractions on the signal detected by surface EMG using the Pelvimeter™ in 16 women. Subjects were asked to perform the following tasks: isolated PFM contractions, isolated abdominal muscle contractions, PFM contractions and abdominal contractions combined,
isolated gluteal muscle contractions, PFM contractions and gluteal muscle contractions combined, isolated hip adductor muscle contractions, and PFM and adductor contractions combined. An EMG signal recorded from the PFMs with an amplitude of greater than or equal to 5mV was found during isolated abdominal contractions in three out of eight women, during isolated gluteal muscle contractions in one out of two women, and during isolated hip adductor contractions in 6 out of 11 women. The detection of an EMG signal during neighboring muscle contractions while the PFMs remain relaxed indicates the possibility of crosstalk from the above muscles. However, as mentioned above, it is difficult to definitively say that the signal recorded by the intravaginal probe was crosstalk and not a PFM contraction in response to facilitation by neighboring muscles.

Based on the proximity of the surrounding musculature to the PFMs, and the above findings, it is highly likely that the intravaginal probes detect EMG signals from neighboring muscles, threatening the validity of recording EMG from the PFMs, however, the distinction between crosstalk and co-activation is very difficult to determine.

2.4.4 Motion Artifact

The other threat to the validity of EMG data recorded using surface electrodes embedded on intravaginal probes is signal contamination from motion artifact. Motion artifact occurs when surface electrodes slide along the skin surface or when the skin beneath the surface electrodes is deformed or stretched, altering the skin’s voltage (Davis, 1959). Either of these situations causes a change in the voltage between the electrode and the skin, causing an artifact to appear in the raw EMG data (Davis, 1959).

When recording surface EMG from most skeletal muscles in the body, motion artifact is markedly reduced by using an adhesive to bind the surface electrode to the skin, reducing movement of the electrodes across the skin, by using silver/silver chloride electrodes which allow
the near instantaneous shifting of ions across the electrode-skin interface, and by using recessed electrodes and a chloride ion solution, again to reduce the capacitive discharge caused by electrode movement across the skin (Gilmore & Meyers, 1983).

When using intravaginal probes, sliding of the electrodes along the vaginal wall may occur during a coughing task, as this task generates a strong and abrupt force directed caudally. Because there is nothing holding the probe in place, the intravaginal probe and its electrodes often move caudally during a cough and can be partially or completely expelled from the vagina.

Methods of minimizing motion artifact usually employed, namely using recessed silver/silver chloride adhesive electrodes, are generally not possible when recording EMG from the PFM. Adhesive electrodes do not adhere to the moist vaginal walls. Furthermore, due to the deep nature of the PFM and the moist environment of the vaginal canal, it is difficult to maintain a chloride ion medium between the vaginal lumen and a silver/silver chloride electrode. Thus, the inability to minimize motion artifact employing the usual methods in combination with the smooth structure of the intravaginal probes and the subsequent movement of the probes during functional tasks make motion artifact a likely threat to the validity of EMG results recorded from the PFM.

Motion artifact is easily detectable in raw EMG data. Any regular EMG burst due to the recording of motor unit activity returns to the baseline within a few milliseconds. Any visible shift away from baseline, lasting greater than 5 milliseconds indicates an artifact (Konrad, 2005). Furthermore, the majority of the power of a signal contaminated by motion artifact is generally found in the low frequency range, below 20 Hz (De Luca, 2002), which can easily be detected using spectral analysis. Unfortunately, many commercially available EMG systems designed for PFM biofeedback provide processed data on a device or computer screen and thus the ability to
inspect the raw EMG data for motion artifact is lost. Using these EMG systems, motion artifact will simply appear as a large spike in EMG data and may be potentially interpreted as representing real changes in PFM activity.

The occurrence of motion artifact when intravaginal probes are used is not reported by most researchers. However, Auchincloss & McLean (2009b) did report the incidence of motion artifact that occurred using the Femiscan™ and Periform™ vaginal probes. When recording EMG using the Femiscan™, 36 out of 240 trials in which women were instructed to cough were contaminated by motion artifact, whereas no incidences of motion artifact were seen using the Periform™. This discrepancy is likely due to the difference in shape of the Femiscan™ and Periform™. The Periform™ may be more resistant to motion artifact than the Femiscan™ since it is wider at the level of the PFMs and tapered at the level of the introitus to prevent movement of the probe, as opposed to being consistently cylindrical along its length.

One strategy used to minimize motion artifact during functional tasks is to have subjects hold the probe to keep it in place. This strategy may result in alterations in the performance of a task and may not completely prevent motion artifact, due to the functional motion of the PFMs during contraction and bearing down maneuvers. The PFMs move upwards and forwards during a contraction (Aukee et al., 2004; Hugosson, 1991) and downwards during a Valsalva maneuver, or bearing down (Hjartardottir, Nilsson, Petersen, & Lingman, 1997). When holding the probe in place, the probe may remain stationary, but the PFMs will still move during contraction or bearing down tasks, possibly resulting in motion artifact (Auchincloss & McLean, 2009b).
2.4.5 Reliability of EMG data Recorded from the Pelvic Floor Muscles Using Intravaginal Probes

Studies investigating the reliability of surface EMG data recorded from the PFMs have reported variable results, partially with respect to the different types of reliability investigated (between-trial or between-day), the types of contraction recorded (short, rapid contractions or sustained contractions), as well as the model of the intravaginal probe used in the study. For the purposes of this review, Currier’s (1990) recommendations have been used to classify reliability coefficients, where a reliability coefficient of less than or equal to 0.69 indicates poor reliability of results, between 0.70 and 0.79 indicates fair reliability, between 0.80 and 0.89 indicates good reliability, and a reliability coefficient of greater than or equal to 0.90 indicates excellent or high reliability.

2.4.5.1 Between-day Reliability

The majority of studies examining the reliability of intravaginal probes in recording PFM EMG have reported between-day reliability. Auchincloss & McLean (2009b) investigated the between-day reliability of both the Femiscan™ and the Periform™. Ten subjects were asked to perform maximal PFM contractions in supine, and were tested one to three weeks apart. Reliability was determined by calculating the intraclass correlation coefficient (ICC) and the mean absolute difference (MAD) between days, normalized to the average of the responses on day 1 and day 2. The Femiscan™ produced poor to fair reliability, with ICC’s ranging from 0.63 to 0.79 and normalized MADs of 20.9 to 30.9 percent. The Periform™ produced fair to good reliability, with ICC’s ranging from 0.79 to 0.89, and normalized MADs of 24.9 to 31.5 percent.

Other studies have found results that conflict with Auchincloss and McLean (2009b). For example, Grape et al. (2009) tested the between-day reliability of peak EMG amplitudes recorded using the Femiscan™ in 15 subjects, evaluated 26 to 30 days apart. Subjects were asked to
perform a maximum voluntary PFM contraction, lasting 10 seconds. High between-day reliability was found when using the peak amplitude recorded during the task (ICC = 0.90, coefficient of variation (CV) of 16.8 percent, where the ICC and CV values are the averages of the ICCs and CVs for the right side of the PFMs, and of the ICCs and CVs obtained for the left side of the PFMs).

It is interesting to note that both Auchincloss & McLean (2009b) and Grape et al. (2009) configured the Femiscan™ electrodes in the same way, i.e. in a differential configuration, and used the peak EMG activity recorded during the task in their statistical analyses, thus, differences in electrode configuration and data processing cannot account for differences in results.

However, whenever ICCs are compared, it is important to realize the impact of between-subject variability. When the range of values for the variables of interest is small (i.e. low between-subject variability), a larger proportion of the variance will be attributed to random error. Error is part of the denominator in the ICC equation (See Section 3.10.2), which can falsely lower the ICC values. The opposite is also true, where high between-subject variability may artificially inflate ICC values. Thus, the difference in ICC values in the above two studies, performed with a similar methodology, may be due to differences in the between-subject variability in each sample, modifying the ICC values calculated.

High between-day reliability of EMG amplitudes recorded using the Periform™ was also reported when tested in five subjects, one week apart. Subjects were asked to perform a three second PFM contraction, and an ICC of 0.98 was found (Thompson, O’Sullivan, Briffä, & Neumann, 2006). The disparity in reliability of the Periform™ compared to Auchincloss & McLean’s (2009b) study may be due to differences in the task, differences in the variance of the samples, as discussed above, or differences in data processing, i.e. whether peak EMG activity or
the average activity recorded over three seconds was used in the statistical analyses. Taking the average activity over a particular timeframe provides a much more stable value, as the average activity will be less sensitive to fluctuations in contractile activity than will the peak EMG activity. However, Thompson et al. (2006) did not provide details regarding variance of their sample or data processing.

A study investigating between-day reliability of EMG amplitudes with a longer timeframe in between the two testing sessions (39 to 122 days) has also been performed using an acrylic vaginal plug (no model given, but likely the SenseRx™ based on picture provided; See Appendix 7.1) with good reliability being shown (ICC = 0.80) during a 10 second maximum voluntary contraction (MVC) of the PFMs (Thorp, Bowes, Droegemueller, & Wicker, 1991). The authors failed to disclose whether values derived from peak EMG activity, or average activity over 10 seconds were used in their statistical analyses, or provide insight into the variance of the sample selected.

The above studies investigating between-day reliability used sustained contractions of greater than three seconds, but the between-day reliability of intravaginal probes during short ‘flick’ contractions was also investigated in the same study by Thorp et al. (1991). Slightly poorer reliability (ICC = 0.76) was found using a vaginal acrylic plug when subjects were instructed to contract and then relax their PFMs as quickly as possible, compared to sustained contractions (Thorp et al., 1991). Details regarding data processing were not provided.

2.4.5.2. Challenges associated with comparing EMG amplitude recorded between days

Many challenges are associated with comparing EMG amplitudes recorded from the PFMs on different days. The first issue is variable positioning of the electrodes relative to the PFMs. A slight variation in the way in which the intravaginal probes are situated may result in
recording activity from different motor units from day to day. Minimization of error due to inconsistent electrode placement can usually be accomplished by visually inspecting the probe’s location and ensuring that the intravaginal probes are centered and are inserted to a similar depth on different days. However, even if the electrodes are situated such that they are recording activity from the exact same motor units on different days, motor unit activation during the same task may vary. It has been well documented that different motor units in a given muscle are activated, depending on the speed of contraction, the amount of force that is required, and the presence of fatigue (Hodson-Tole & Wakeling, 2009). Motor unit activation is also influenced by auditory and visual feedback, proprioceptive inputs, and cutaneous stimulation (Hodson-Tole & Wakeling, 2009). As such, it is unlikely that the same motor units are activated during the same task, performed on different days. Each motor unit has a characteristic amplitude and frequency associated with it, thus, recording EMG from different motor units will influence the signal amplitude and frequency characteristics of the EMG data recorded.

Other challenges associated with comparing EMG data recorded on different days include “varying temperature and ... moisture within the vaginal lumen, [which] is almost impossible to control” (Brown, 2007), both factors having an effect on the recorded signal.

The last factor that makes it difficult to compare values obtained from EMG recorded on different days is variable subject performance. As seen in Section 2.4.5.1, a common task used when determining reliability of EMG results is an MVC. This task requires a voluntary contraction. Even though instructions to contract maximally are given, there is no way to guarantee that a maximal performance is being consistently delivered. Auchincloss & McLean (2009b) reported high variability in data recorded between days during an MVC task. This
variability may be related to recording parameter issues, but it is also likely related to variable subject performance.

Performance is modified by factors such as fatigue, pain, discomfort, environmental conditions, as well as motivation. As such, subject performance is likely to vary if variations in any of the above factors exist between days. Brown (2007) documented participant reports of the above performance-modifying factors, and found pain, discomfort, fatigue, and difficulty performing a task to be an issue during one of the two evaluation sessions in subjects for which changes in peak PFM EMG activity between days was shown to be an issue.

Variability in performance between days due to performance-modifying factors is further exacerbated by the fact that many women cannot correctly contract their PFMs (Enck & Vodusek, 2006). Bo et al. (1988) found that approximately 30 percent of women were unable to perform a proper PFM contraction. The inability to perform a proper PFM contraction has been reported in other studies as well (Bo & Stien, 1994; Brown, 2007). Thus, inconsistent performance is highly likely to be an issue in women who are unable to perform a proper PFM contraction in the first place. It should be noted that women in most of the studies discussed in Section 2.5.4.1 were assessed prior to participation in order to ensure they were able to perform a “proper PFM contraction” but were not evaluated in terms of consistency. Because there is no way to gage subject performance to ensure a similar performance is delivered between days, we cannot be certain if inconsistent results between days are due to varying subject performance or to variation inherent in the recording parameters.

2.4.5.3 Between-day Reliability of Other Skeletal Muscles

Although between-day reliability of recording EMG from the PFMs is at times questionable, the consistency of EMG results between days when recording activity from other
skeletal muscles in the body does not seem to be any more consistent than that of the PFMs. For example, Dankaerts, O’Sullivan, Burnett, Straker, & Danneels (2004) investigated the between-day reliability of trunk muscle activity recorded by surface EMG in 11 subjects, and found that the between-day reliability of peak EMG amplitudes recorded during an MVC task ranged from extremely poor to high (ICC = 0.19-0.99, percent standard error of measurement (SEM) = 4-36%). Kollmitzer, Ebenbichler, & Kopf (1999) found similar results when recording surface EMG from the quadriceps muscles, with the reliability of EMG amplitude during an MVC task performed on different days being poor (Pearson’s correlation coefficient ranging from 0.35 to 0.52).

Larsson, Karlsson, Eriksson, & Gerdle (2003) evaluated the between-day reliability of EMG amplitudes from the knee extensors during an MVC of the knee extensors task in 20 subjects, and found poor to good reliability (ICC=0.65-0.89). Thus, clearly this issue of questionable between-day reliability, possibly due to variability in electrode positioning, motor unit activation, and/or subject performance during maximal contractions, is not restricted to the PFMs, but applies other skeletal muscles as well.

Despite the evidence that questionable between-day reliability of surface EMG recordings is not restricted to the PFMs, no study has investigated differences in between-day reliability of EMG recordings from both the PFMs and a peripheral muscle in the same subjects performing the same protocol.

2.4.5.4 Between-trial Reliability of the Pelvic Floor Muscles

Between-trial reliability of recording EMG using the intravaginal probe design has also been investigated. The three studies investigating between-trial reliability have produced consistent results. The study by Auchincloss & McLean (2009b) also contained a between-trial
reliability component, and found fair to high reliability for recording peak EMG amplitude using the Femiscan™ (ICC = 0.72 to 0.98, CV=8.5% to 14.2%) and good to high reliability for the Periform™ (ICC = 0.87 to 0.96, CV=9.6% to 12.9%) during supine PFM MVCs. Grape et al. (2009) also found high between-trial reliability (ICC = 0.90, CV=14.3%) when using the Femiscan™ during an MVC task, in 17 subjects. Aukee, Penttinen, Immonen, & Olavi (2002) also reported good between-trial reliability of peak EMG amplitude when using the Femiscan™ to record PFM activity in 11 subjects, during short ‘flick’ contractions. Thus, although only three studies have investigated between-trial reliability, the consensus seems to be that the intravaginal probes do generate good between-trial reliability when recording peak EMG from the PFMs.

2.5 Proposed Alternatives to Intravaginal Probes

Despite the research exposing the drawbacks of the intravaginal probes currently in use, only one alternative electrode design has been developed, the IVS-2 intravaginal sensor (SRS Medical, Redmond, WA). This sensor consists of a frame similar in shape and size to a penny onto which three gold electrodes are mounted. When inserted into the vagina, one gold electrode positioned on the ‘face’ of the penny-shaped frame faces the posterior aspect of the pubis (SRS Medical, Sales representative, oral communication, 2010), presumably to act as an internal reference. One active electrode is positioned on each side of the frame in order to record PFM activity. Although the IVS-2 design is an improvement on the intravaginal probe designs currently available due to its smaller diameter and relatively small electrode size, this design is still highly flawed. First, the IVS-2 is even less resistant to movement during functional tasks compared to certain models of intravaginal probes (SRS Medical, Sales representative, oral communication, 2010), as it may be essentially be free-floating in some women. Furthermore, the IVS-2 uses a ‘faux’ differential configuration, as the resultant EMG signal recorded is an
aggregate of the right and left sides of the PFMs (SRS Medical, Sales representative, oral communication, 2010). Thus, one cannot record EMG activity from the right and left PFMs separately and crosstalk may still occur. The IVS-2’s psychometric properties have not been tested as of yet.

2.6 Summary

Based on the literature reviewed, the intravaginal probe designs used to record surface EMG from the PFMs have many drawbacks, including deformation of the vaginal wall and pelvic floor anatomy, discomfort upon insertion, nonspecific results concerning which PFMs are being examined, and likely contamination of EMG data by crosstalk and motion artifact. There is also some question regarding the reliability of results, especially between days or when examining muscle activity during short, maximal effort contractions.

Despite the research exposing the drawbacks of the intravaginal probes currently in use, an optimal surface electrode design is not commercially available. Dr. L. McLean and Mr. R. Young have designed a novel electrode that overcomes some of the limitations noted in this review, but its psychometric properties have not been tested. This study was undertaken to address this need. The test-retest reliability and validity of a novel, theoretically superior electrode for recording surface EMG from the PFMs was investigated and compared to the Femiscan™. The reliability of EMG results obtained from the PFMs was also compared to the reliability of recording EMG from a more easily accessible skeletal muscle, the biceps brachii. Facets of reliability included between-trial and between-day reliability, using data from both voluntary and involuntary contractions. Facets of validity included the incidence of motion artifact contamination during coughing using each vaginal electrode, as well as the recording of crosstalk at the PFMs during nearby muscle contractions. The Femiscan™ was chosen for
comparison to the novel electrode, as it is the only intravaginal probe available that allows its electrodes to be arranged in a true differential configuration, and was found by Auchincloss and McLean (2009a) to have a superior performance with respect to crosstalk when compared to the Periform™ probe. The biceps brachii were chosen as our comparison skeletal muscle, due to the ability to theoretically provoke an involuntary muscle contraction from the PFM s and biceps simultaneously using the same task.
Chapter 3

Methods

3.1 Objectives

The aims of the current study were to:

1. Determine the between-trial reliability of EMG data recorded from the PFMs using the novel electrode and compare it to that recorded using the Femiscan\textsuperscript{TM}, when different tasks and test positions (supine and standing) were used.

2. Determine the between-day reliability of EMG data recorded from the PFMs using the novel electrode and compare it to that recorded using the Femiscan\textsuperscript{TM}, when different tasks and test positions (supine and standing) were used.

3. Compare the between-trial and between-day reliability of surface EMG data recorded from the PFMs to the between-trial and between-day reliability of surface EMG recorded from the biceps brachii muscles.

4. Determine the prevalence of motion artifact contamination in PFM EMG data recorded during coughing tasks when utilizing the novel electrode and compare it to the prevalence of motion artifact contamination in data recorded using the Femiscan\textsuperscript{TM}.

5. Determine the effect of muscle contractions from the hip adductors, hip external rotators, and transversus abdominis on the EMG signals recorded at the PFMs using the novel electrode and compare these to the effect on the EMG signal recorded using the Femiscan\textsuperscript{TM}.
6. Determine the acceptability of utilizing the novel electrode, in terms of physical comfort, and compare it to the acceptability of utilizing the Femiscan™ to record EMG data from the PFMs, in healthy women.

3.2 Novel Electrode Description

The design of the novel electrode was based on the transurethral EMG electrode described by Stafford, Sapsford, Ashton-Miller, & Hodges (2010). The novel vaginal electrode tested in the current study consists of a suction surface head onto which two small stainless steel electrodes, arranged in a differential configuration, are attached (See Figure 3-1). Each electrode has a surface area of 1mm² and the interelectrode distance between electrode pairs is 1 cm. The suction surface head is connected to 30 cm of catheter tubing through which the electrode leads pass. This tubing, in turn, is connected to a stopcock and a syringe (See Figure 3-2). The withdrawal of air from the syringe causes a suction force to be generated at the surface head. The stopcock can be closed to maintain suction at the electrode site. Thus, when the suction surface head is placed against the lateral vaginal wall adjacent to the PFMs, it will adhere to the vaginal wall once the suction is applied. A separate differential electrode pair can be attached to each side of the vaginal wall in order to record activity from the right and left PFMs separately. Each pair has the electrode leads coupled to the input of the EMG amplifiers.

Figure 3- 1: Surface head of novel electrode
3.3 Study Design

This study used an observational design, investigating the psychometric properties of a new surface electrode, using healthy women as the participants. Psychometric properties determined when using the novel electrode were compared to those obtained when utilizing the Femiscan™ as well as Delsys™ D.E.2.1 surface electrodes adhered to the skin surface over the biceps brachii muscle. Ethics approval was obtained from the Queen’s Research Ethics Board (REH-470-10) prior to the initiation of participant recruitment (See Appendix 7.2).

3.4 Sampling

Convenience, nonrandom sampling was used to obtain 20 subjects. Monetary compensation was provided upon completion of the study. Recruitment methods included word of mouth, flyers posted around Queen’s University’s campus (see Appendix 7.3), and an advertisement in the Queen’s Gazette (see Appendix 7.4).

Nulliparous women between the ages of 18 and 50 who were functional in English were included. Women with a history of pelvic organ prolapse, incontinence, or gynecological surgery such as a hysterectomy were excluded, as these conditions may be associated with abnormal PFM function (Jackson & Naik, 2006; Ospelt, 2006). Women diagnosed with any neurological condition known to influence muscle contractile ability, or who had active vaginal infections
were also excluded. Women with a history of chronic low back pain, or musculoskeletal conditions affecting the lower extremity in the past 6 months were also excluded, as they may not have been able to perform the parts of the protocol involving lower extremity movement. Participants were screened for these inclusion and exclusion criteria using self-report.

3.5 EMG System Specifications

A Delsys Bagnoli\textsuperscript{TM}-16 EMG amplification system (CMRR = 90 dB at 60 Hz, bandwidth 20–450 Hz with a notch filter at 60 Hz, input impedance > 10\textsuperscript{15} Ohms, overall noise \leq 1.2 \mu V) was used with an overall gain of 1000 for each EMG channel. All EMG channels were interfaced with Delsys\textsuperscript{TM} D.E. 2.1 pre-amplifiers. EMG data were digitized using a 16 bit National Instruments (PCI-MCIAEIC) analog to digital (AD) Converter, using a ±5 V range, and recorded using EMGWorks—Acquisition\textsuperscript{TM} software (Delsys\textsuperscript{TM}, Boston, MA), using a sampling rate of 1000 Hz.

3.6 Procedure

Potential participants indicating interest in the study were instructed to contact the primary investigator by phone. During the initial conversation, the study was described, outlining the data collection protocol and inclusion and exclusion criteria. If a potential participant met all eligibility criteria and was interested in participating, an initial appointment was set up whereby the participant provided informed consent (see Appendix 7.5) and was familiarized with the instrumentation and methods.

The first visit to the Pelvic Floor Laboratory took approximately 30 minutes. At this time, written consent was obtained. Next, the participant was taught how to perform a correct PFM contraction, which was verified by the investigator through vaginal palpation and visual inspection of the surrounding hip and abdominal musculature to check for attempted strategies of
substitution. In order to facilitate a PFM contraction, the investigator used cues such as “squeeze your pelvic floor muscles as though trying to hold urine”, or “using your pelvic floor muscles, squeeze my finger”. The task was repeated another two times once a correct, isolated PFM contraction was achieved.

Additionally, the participant was taught how to perform resisted hip adduction and resisted external rotation contractions while either maintaining relaxation in the PFMs or maximally contracting the PFMs. Participants adopted the positions to be used during data collection, to familiarize them with the procedure. The examiner then applied a manual resistance to the hip movements and measured the force generated using a hand-held dynamometer, again to familiarize them with the procedure. The investigator palpated the skin overlying the central tendon of the perineum in order to monitor the absence or presence of a PFM contraction during attempts to contract the hip musculature in isolation or in combination with the PFMs, respectively. While teaching the participant to contract the hip adductors in isolation, the examiner visually inspected the contralateral hip adductors to ensure that the movement was isolated to the leg being tested. During the hip external rotator contractions, the hamstrings and gluteal muscles were visually inspected to ensure that the movement was as isolated as possible to external rotation. If any of the above movements were performed incorrectly, the examiner cued the participant to make the appropriate correction.

Finally, participants were taught how to perform a maximal isometric biceps brachii contraction, using a tabletop as a resistance to elbow flexion. Once each task was performed correctly, it was repeated twice more to ensure the subject was able to consistently perform the task.
This concluded the familiarization session. Participants were given an exercise sheet and asked to practice each movement 10 times per day, over the next 2 days (See Appendix 7.6). Participants returned within one week to complete the data collection protocol.

3.7 Data Collection Protocol

Data were collected over two sessions, the first lasting approximately 2 hours, and the second lasting approximately 45 minutes. At the beginning of each session, participants were instructed to void in order to standardize bladder fullness. If participants were menstruating on the day of their scheduled session, their session was rescheduled to occur after their period had ended.

3.7.1 Instrumentation

Differential surface electrodes (Delsys™ D.E. 2.1; 10 mm by 1 mm electrode bars with an interelectrode distance of 10 mm) were adhered to the skin overlying the biceps brachii bilaterally using double-sided Delsys™ adhesives. Skin preparation (abrading the skin over the electrode site using gauze soaked in rubbing alcohol) was performed before the electrodes were positioned on the skin over the muscle bulk of the biceps brachii, over a line drawn between the cubital fossa and the medial acromion (The SENIAM group, 2010). Positioning of the electrodes over the muscle bulk was verified though visualizing an isometric contraction of the biceps brachii muscles. The distance between the cubital fossa and the centre of the electrodes was measured when the participant’s elbow was passively held in 90 degrees of flexion. This distance, in centimetres, was recorded on the data collection sheet in order for the same electrode site to be replicated on the second day of testing.
The order of the PFM electrodes (Femiscan™ vs novel electrode) was randomized between participants using a randomization table. All tasks were first performed with one type of electrode in situ, and then repeated with the other electrode in situ.

The examiner inserted the novel electrodes, in order to ensure correct positioning over the medial portion of the pubococcygeus muscle. One novel electrode was positioned on each side of the vaginal wall, adjacent to the pubococcygeus muscles, in order to record activity from the right and left PFMs separately. Placement of the electrode was determined through manual palpation. Once the muscle bulk of the pubococcygeus muscle was palpated, the investigator inserted the suction surface head into the vagina, and firmly but comfortably pressed it onto the vaginal wall overlying the muscle bulk. The participant was then asked to assist with the procedure by withdrawing approximately 0.5 mL of air from the syringe. The participant was asked to withdraw the air in order to ensure that they were comfortable during the application of the suction. The participant was informed that during the withdrawal of air, they may feel nothing at all, or some slight pressure, however, no discomfort or pain should be felt at any time. Once the suction was applied, the examiner then closed the stopcock to maintain the suction force, and then tested to ensure that adequate suction was applied to hold the electrode in place by gently tugging on the catheter tubing to make sure that this did not dislodge the electrodes.

The participant was able to insert the Femiscan™ herself, such that the protrusion on its outer end rested comfortably on the caudal aspect of the pubic bone. The examiner verified appropriate positioning of the Femiscan™ through visual inspection. Subjects always wore underwear to help keep the Femiscan™ in place. In both cases, a reference surface electrode was adhered to the skin overlying the right anterior-superior iliac spine.
The following tasks were performed over two sessions. Unless specified, three repetitions of each task were performed, with 30 second rest periods between repetitions.

### 3.7.2 Reliability Protocol (Performed on both the first and second evaluation sessions)

*Reliability of surface EMG amplitude recorded from the biceps brachii*

In order to determine the between-trial reliability of surface EMG amplitude recorded from the biceps brachii muscles, participants were asked to perform three maximal effort elbow flexion contractions of each arm, each repetition lasting approximately three seconds.

Participants were positioned in standing with their hips and knees bent, and with their upper body leaning over a sturdy table top. One arm was braced on top of the table, while the forearm on the side to be tested was fully supinated and positioned just underneath the tabletop (See Figure 3-3). Participants were asked to adjust the amount of hip and knee flexion such that the elbow of the forearm under the table was flexed to 90 degrees. Participants were asked to try push up on the underside of the table top. Standardized verbal encouragement was provided by the examiner, throughout the task. The task was then repeated with the other arm.

![Figure 3- 3: Testing position used for bicep maximal voluntary contractions](image)
The participants also performed a “catch a load” task. This was a standardized task in which the participant was standing with their feet shoulder width apart, elbows flexed to 90 degrees and hands holding a milk crate.

The participant was given a general instruction to relax as much as they could while maintaining the above position, and the examiner then dropped a 1 kg load from a height of 30 cm directly above the crate. Participants were instructed to catch the load such that the crate did not move vertically. EMG data were recorded from the PFMs and biceps brachii simultaneously, as this task was chosen to elicit an involuntary contraction from both muscle groups.

*Reliability of surface EMG amplitude recorded from the PFMs*

In order to determine between-trial reliability of the novel electrode and the Femiscan™, participants were asked to perform two tasks. The first was an MVC of the PFMs. For this task, participants were positioned in crook lying, with one pillow underneath their head. A strap was placed around the distal thighs to allow the participants’ legs to relax into slight abduction while eliminating the need for hip muscle contractions during the task.

Participants were asked to contract their PFMs, as though they were trying to hold urine, as hard as they could. Participants began contracting their PFMs when given the verbal cue to ‘squeeze’. The contraction lasted approximately three seconds and verbal encouragement was given throughout.

The other task that participants performed was the “catch a load” task described above. The response of the PFMs to such a loading task has been demonstrated in the literature (Smith et al., 2007). This task was included to minimize within subject differences, as the response of the PFMs to a loading task is involuntary, as opposed to a voluntary maximal contraction of the
Anything requiring voluntary muscle activity was thought to be more prone to variations in performance than involuntary activity.

**3.7.3 Motion Artifact Protocol** (Performed on the first evaluation session only)

In order to determine the prevalence of motion artifact contamination in functional tasks, participants were asked to perform 10 repetitions of a single barrel maximal effort cough, with each vaginal electrode in situ. Participants were instructed to take a deep breath in, and cough as hard as they could. Women were positioned in crook lying to perform this task.

**3.7.4 Crosstalk Protocol for the Hip Musculature** (Performed on the first evaluation session only)

In this study, we investigated the effect of hip adductor and hip external rotator contractions on the EMG amplitude recorded from the PFMs. Although the gluteal muscles were also identified as a possible source of crosstalk when recording surface EMG from the PFMs (see Section 4.3), the gluteal muscles are located closest to the ischiococcygeus muscles. Because the novel electrode was placed on the vaginal wall adjacent to the pubococcygeus muscles, crosstalk from the gluteal muscles was less likely to be an issue than it would have been if the PFMs were studied using anal electrodes. The hip adductors and external rotators were expected to pose a much more serious threat to the validity of the EMG signal recorded from the pubococcygeus muscles, therefore, only the effect of contractions of these muscles was investigated in the main protocol of this study. A separate experiment was performed to investigate crosstalk from the transversus abdominis muscle when recording muscle activity from the PFMs. This separate protocol is described in Section 3.7.5. The order of hip muscle contractions (hip adductor tasks or external rotator tasks) was randomized using a randomization table.
3.7.4.1 Effect of hip adductor contractions

In order to determine the effect of unilateral hip adductor contractions on the signal recorded from the PFMs, two streams of tasks were performed. The first stream of tasks comprised isolated unilateral hip adductor contractions performed at various intensities (maximal effort, 25 percent of maximal effort, and 50 percent of maximal effort) while the participant was asked to keep her PFMs relaxed. The second stream of tasks comprised maximal PFM contraction tasks in combination with unilateral hip adductor contractions at various intensities (maximal effort, 25 percent of maximal effort, and 50 percent of maximal effort). Both streams of tasks were included in order to maximize our ability to determine if crosstalk was a problem, despite possible co-activation and variability in subject performance.

Unilateral hip muscle contractions were performed while recording EMG from both sides of the PFMs, as opposed to bilateral hip muscle contractions, as we wished to determine whether or not crosstalk was an issue during ipsilateral hip contractions only or during contralateral hip contractions as well.

A range of intensities was included, as it is important to determine whether or not crosstalk is an issue at maximal and submaximal hip contraction levels, and to have an understanding of at what approximate intensity crosstalk becomes an issue, if it is an issue at all.

During isolated hip adductor contractions, the participant was positioned in sidelying, with leg to be tested (right) in the dependent position. The left knee was flexed such that the left foot was firmly planted on the plinth (See Figure 3-4). First a maximal isolated hip adductor contraction was performed. After collecting approximately two seconds of EMG data when both the PFMs and hip adductors were relaxed, participants then lifted their foot approximately 10 cm off the plinth, keeping their knees straight. The examiner then applied a manual resistance using
a hand-held dynamometer, approximately 6.5 cm proximal to the tibiofemoral joint. The examiner applied a gradual force to push the limb back onto the plinth, and the participant was instructed not to let the examiner move their leg. Two more repetitions of this task were performed, with 30 second rest periods in between contractions. The examiner took note of the maximal force attained during each repetition, and then took the average of the dynamometer readings during maximal hip adductor contractions as the maximal force output for the hip adductors. The examiner then calculated the amount of force the participant needed to generate in order to reach the desired 25 percent and 50 percent of maximal force determined during the MVCs. EMG data were then recorded from the PFMs while participants performed hip adductor contractions at 25 percent and 50 percent of their maximum contraction intensity. In order to achieve the desired output, the examiner adjusted the amount of force exerted onto the limb by monitoring the force output indicated by the dynamometer at each point in time, and told the participant to match the manual resistance provided. Once the appropriate contraction level was achieved, the participant was asked to hold the hip muscle contraction and relax their PFMs. The examiner monitored the force output using the dynamometer throughout to ensure that the participant did not decrease hip force outputs while relaxing their PFMs.

In order to aid in data processing, the examiner used a footswitch during data collection to indicate at which point the hip adductor contraction began. During submaximal contractions, the footswitch was also used to indicate when the target force output was reached. During maximal hip contractions, the footswitch was used in order to indicate when the hip contraction was broken by the examiner.
Next, combined PFM and hip adductor contractions were performed. Participants were positioned as above. Maximal PFM contractions were combined with maximal, 25 percent of maximal, and 50 percent of maximal hip adductor contractions. Participants were instructed to squeeze their PFMs as hard as they could. After approximately two seconds, they were then cued to lift their leg off the bed and not to let the examiner move their leg while keeping their PFMs maximally contracted. This combined PFM and hip contraction was held for approximately five seconds. For the submaximal hip adductor contractions, the examiner adjusted the amount of force exerted onto the limb by monitoring the force output indicated by the dynamometer at each point in time, and told the participant to match the manual resistance provided. Once the appropriate force output was achieved, the participant was asked to hold the hip muscle.
contraction and was then reminded to keep squeezing their PFMs as hard as they could. The examiner again used the footswitch as above.

### 3.7.4.2 Effect of hip external rotation contractions

In order to determine the effect of hip external rotator (including obturator internus) contractions on the EMG signal recorded from the PFMs, a protocol similar to the one used to determine the effect of hip adductor contractions was used. Ideally, because obturator internus is a possible synergist of the PFMs, EMG from the obturator internus would be recorded simultaneously with the PFM EMG in order to assess cross-correlations between the channels (see description of transversus abdominis protocol in Section 3.7.5). This was not possible, however, as such recordings from the obturator internus were beyond the capabilities in our laboratory (L. McLean, personal communication, 2010).

Instead, two streams of tasks were performed. The first comprised isolated hip external rotator contractions at varying intensities (maximal effort, 25 percent of maximal effort, and 50 percent of maximal effort) while the participant was asked to keep her PFMs relaxed. The second comprised maximal PFM contractions combined with hip external rotator contractions at varying intensities (maximal effort, 25 percent of maximal effort, and 50 percent of maximal effort).

For all tasks involving the hip external rotators, the participants were placed in prone, with the hip in neutral rotation and 0 degrees of extension, and with the knee of the leg to be tested (right) flexed to 90 degrees (See Figure 3-5). A strap was placed around the plinth and participant, at the level of the posterior superior iliac spine in order to increase the participant’s stability during the task. The examiner applied a gradual manual resistance, quantified by a hand-held dynamometer, placed approximately 6.5 cm proximal to the medial malleolus to push the limb into internal rotation.
For the isolated maximal hip external rotator contractions, after collecting approximately two seconds of rest data, the participant was instructed not to let the examiner push their right lower leg outwards toward the floor, and to keep their PFMs as relaxed as possible. The average force output from three trials, indicated by the hand-held dynamometer, was then used to determine the force output necessary by the participant in order to reach 25 and 50 percent of their maximum intensity. For the submaximal hip external rotator contractions, the examiner graded the amount of force exerted on the limb, monitoring the force output reading on the dynamometer. Once the appropriate force output was achieved, the participant was asked to hold the hip external rotator contraction and relax their PFMs. The examiner monitored the force output throughout to ensure that the participant did not decrease hip force outputs while relaxing the PFMs. A footswitch was used during this task in the same way as for the hip adductor tasks.

Figure 3-5: Participant and investigator’s testing position during tasks involving hip external rotator contractions
For the combined PFM and hip external rotator contractions, maximal PFM contractions were combined with maximal effort, 25 percent of maximal effort, and 50 percent of maximal effort hip external rotator contractions. Participants were instructed to contract their PFMs maximally. After approximately two seconds, the participant was verbally cued to begin resisting the force applied to their lower leg by the examiner’s manual resistance. This combined PFM and hip contraction was held for approximately five seconds. For the submaximal hip external rotator contractions, the examiner adjusted the amount of force exerted onto the limb by monitoring the force output indicated by the dynamometer at each point in time, and told the participant to match the manual resistance provided. Once the appropriate force output was achieved, the participant was asked to hold the hip muscle contraction and then was reminded to keep squeezing their PFMs as hard as they could.

The examiner again used a footswitch in order to indicate the point at which the hip external rotator contraction began, and, during submaximal hip contractions, when the target force output was reached. During maximal hip contractions, the footswitch was used to indicate when the hip muscle contraction was broken by the examiner’s manual resistance.

This concluded the tasks required on the first day of data collection. At this time, participants were asked if they would like to participate in a second, related study, involving examining the effect of abdominal contractions on the signal recorded from the PFMs. If the participant agreed to participate in this separate study, a separate consent form and letter of information (see Appendix 7.7) was given to them to look over at their leisure. If the participant declined being involved in the related study, it bore no consequence on their participation in the main study. All participants returned approximately one week later to complete the second evaluation session.
On the second evaluation day, the vaginal electrodes and biceps brachii electrodes were positioned as described above in Section 3.8.1. In order to maximize consistency regarding placement of the biceps brachii electrodes, the distance recorded between the cubital fossa and the centre of the biceps brachii electrode on the first data collection day was used to determine electrode placement on the second evaluation day.

In order to determine between-day reliability of the EMG data recorded from the PFMs and bicep muscles, all tasks that were part of the Reliability Protocol performed during the first evaluation session (see Section 3.8.2) were repeated during the second evaluation session.

At the end of this second evaluation session, participants were asked to rate the acceptability of the insertion of each vaginal electrode in terms of physical comfort, using a verbal numeric scale from zero to ten. Zero was described as ‘very acceptable’, and ten was described as ‘unacceptable’/‘would never agree to use the electrode again’. Participants were also asked to rate the acceptability of position changes with each vaginal electrode in situ, in terms of physical comfort, using the same verbal numeric scale.

Finally, demographic information including age, obtained through self-report, and weight and height, measured in the laboratory, were collected.

For those who agreed to participate in the separate study involving the investigation of crosstalk originating from the transverses abdominus muscles on EMG recordings from the PFMs, a third laboratory session lasting approximately 1.5 hours was scheduled at the participant’s leisure.

3.7.5 Crosstalk Protocol for the Transversus Abdominis

The effect of transversus abdominis contractions on the EMG signal recorded from the PFMs was determined in a different way than what is described above for the hip external
rotators, as it was feasible to safely insert fine wire electrodes into the transversus abdominis muscle, and to record EMG from the transversus abdominis muscle and PFMs simultaneously. Ideally, selective muscle activation of the transversus abdominis would have been performed using electrical stimulation; however, this method was beyond the capabilities of our laboratory. In total, five of the twenty participants agreed to perform this protocol on a separate, third evaluation session. Participants involved in this separate study provided informed written consent at the start of the third data collection session.

In order to record EMG from the transversus abdominis, one pair of fine wire electrodes (Calgren Enterprises, Inc., Gilroy CA. 221-28SS-730) was inserted into the right transversus abdominis muscle using a needle cannula. In order to guide the insertion of the electrodes into the transversus abdominis muscle, an approach currently being used in our laboratory, involving the monitoring of EMG signals while inserting the electrodes was used. The transversus abdominis is the deepest abdominal muscle, covered by the internal obliques and external obliques. It has been well documented that some motor units in a specific muscle will fire in response to the insertion of a wire into the muscle. This response is known as insertional activity (Preston & Shapiro, 2002). Because a needle cannula encasing the fine wire electrodes had to pass through the internal and external obliques before arriving at the transversus abdominis muscle, insertional activity was observed at distinct points in time when inserting the needle cannula first into the external oblique muscle, and then when inserting the needle cannula into the internal oblique muscle. Thus, the third burst of insertional activity seen when monitoring the EMG signal indicated that the needle had entered the transversus abdominis muscle. Confirmation of the electrode position within the transversus abdominis was performed by instructing the individual to draw their navel inwards, towards their spine (abdominal hollowing maneuver) and to breathe out against pursed lips
(forced expiration), as both tasks have been shown to preferentially activate the transversus abdominis (Hodges, Gandevia & Richardson, 1997). If the electrodes were inserted correctly, sharp bursts in motor unit activity were seen in the EMG signal recorded during these tasks. Once the electrode location was confirmed, the needle cannula was removed, leaving the fine wire electrodes in situ.

Because fine wires were used for this protocol, the EMG bandwidth employed was increased to 20-2000Hz, and the sampling rate was increased to 2000Hz for the tasks involving the transversus abdominis. All other EMG system specifications were identical to those described in Section 3.5.

The following tasks were performed first with one vaginal electrode in situ, and then with the other vaginal electrode in situ. Using these vaginal electrodes, EMG activity was recorded from the right PFMs only.

Participants were positioned in crook-lying, and were asked to contract their transversus abdominis, by drawing in their navel towards their spine. Participants had been previously instructed how to perform this task in order to confirm the location of the fine wire electrodes. Over a period of 60 seconds, the participants were asked to perform a cycle of 10 maximal contractions and subsequent relaxations of the transversus abdominis. Three repetitions of this task were performed. These data were then used to provide the participant with a real-time visual representation of their muscle activity, normalized to their maximal transversus abdominis effort. Using this visual representation, participants were asked to monitor their muscle activity, and perform a cycle of 10 transversus abdominis contractions and subsequent relaxations at 25 percent of MVC and 50 percent of MVC. Three repetitions of each task were performed.

Table 3-1 summarizes the tasks that were performed on each evaluation day.
| 1. | Biceps brachii MVC (right and left sides tested separately) |
| 2. | Catch a load task |
| 3. | Isolated maximal PFM contraction |
| 4. | Maximal single barrel cough |
| 5. | Isolated maximal right hip adductor contraction (no PFM contraction) |
| 6. | Isolated 25% MVC of right hip adductors (no PFM contraction) |
| 7. | Isolated 50% MVC of right hip adductors (no PFM contraction) |
| 8. | MVC of the PFMs + MVC of the right hip adductors |
| 9. | MVC of the PFMs + 25% MVC of the right hip adductors |
| 10. | MVC of the PFMs + 50% MVC of the right hip adductors |
| 11. | Isolated maximal right hip external rotator contraction (no PFM contraction) |
| 12. | Isolated 25% MVC of the right hip external rotators (no PFM contraction) |
| 13. | Isolated 50% MVC of the right hip external rotators (no PFM contraction) |
| 14. | MVC of the PFMs + MVC of the right hip external rotators |
| 15. | MVC of the PFMs + 25% MVC of the right hip external rotators |
| 16. | MVC of the PFMs + 50% MVC of the right hip external rotators |

| Day 2 |
| 1. | Biceps Brachii maximal contraction (right and left sides tested separately) |
| 2. | Catch a load task |
| 3. | Isolated maximal PFM contraction |

| Day 3 (Optional) |
| 1. | Cycle of maximal transversus abdominis contractions |
| 2. | Cycle of 25% MVC transversus abdominis contractions |
| 3. | Cycle of 50% MVC transversus abdominis contractions |

Table 3-1: Summary of tasks performed on each evaluation session

3.8 Data Processing

Data processing was performed using EMGWorks Analysis (v.4.0) and Matlab (v.2009) software. The raw EMG data from the reliability protocol (Section 3.8.2) and crosstalk from the hip musculature protocol (Section 3.8.4) were full-wave rectified, and smoothed by calculating the root-mean square (RMS) value using a sliding window of 200 ms length and an overlap of 199 ms. EMG data files from the transversus abdominis protocol (Section 3.8.5) were truncated.
after 10 contractions and relaxation cycles of the transversus abdominis had been performed, and were then filtered using a third order Butterworth filter with a cutoff of 20 Hz. EMG data from the motion artifact protocol (Section 3.7.3) were left as raw data.

3.8.1 Between-trial and Between-day Reliability

For the PFM MVC, bicep MVC, and “catch a load” tasks, the peak rectified and filtered RMS amplitude was chosen to represent the muscle activity from each file. These peak RMS values were used in the reliability analyses.

3.8.2 Motion Artifact

For each cough, the power spectrum was calculated using a one second window from the raw EMG data that encompassed the start and end of the cough. Since motion artifact has frequency contributions below 20 Hz (De Luca, 2002), for each file, the peak power in the 1 to 20 Hz range was determined and was compared to the average power in normal physiological range (20-250 Hz). If the peak power in low frequency range was greater than the average power in the normal physiological range, motion artifact was deemed to be present. If the peak power in the low frequency range was less than the average overall power in the normal physiological range, motion artifact was deemed to be absent.

3.8.3 Crosstalk from the Hip Adductors and External Rotators

EMG amplitudes were required while the hip was relaxed and while the target hip force output was maintained (i.e. 25, 50 and 100% hip MVC). The footswitch data were used in order to determine the portion of each data file that was associated with the appropriate hip muscle contraction force. For example, during the isolated hip muscle contractions, the value representing the EMG amplitude recorded when the hip was relaxed was determined by taking
the average activity over one second, ending 0.5 seconds before the footswitch was triggered, indicating that the hip contraction had begun.

For submaximal isolated hip contractions, the value representing the PFM EMG amplitude recorded when the target hip force was maintained was determined by taking the lowest PFM EMG amplitude recorded after the second footswitch was triggered, indicating that the target hip force output was reached. The lowest PFM EMG amplitude was chosen since the participants were verbally cued to relax their PFMs after the second footswitch was triggered. The investigator continually monitored force output on the dynamometer to ensure that the hip contraction force was maintained while the participant concentrated on relaxing the PFMs. The lowest PFM EMG amplitude recorded after the second footswitch was triggered was thought to be more representative of crosstalk as opposed to co-contraction of the PFMs.

For isolated maximal effort hip contractions, the PFM EMG amplitude recorded when the target hip force output was reached was determined as the lowest rectified and smoothed PFM EMG amplitude recorded during the final one second of the contraction.

During the combined PFM and hip muscle contraction tasks, the value representing the PFM EMG amplitude recorded during an isolated PFM MVC (when the hip was relaxed) was determined by taking the peak RMS amplitude generated prior to the first footswitch being triggered, which indicated the beginning of the hip muscle contraction. During submaximal combined PFM and hip muscle contractions, the peak PFM EMG amplitude recorded when the participant performed the PFM MVC and a concurrent hip muscle contraction was determined by taking the peak RMS amplitude recorded after the second footswitch had been triggered, which indicated that the target hip force output had been reached. In this case the peak RMS value was used in the data analyses, since the participants were reminded to keep their PFMs maximally
contracted during the hip contraction task. Thus, the peak value is more representative of the EMG amplitude generated during a PFM MVC combined with the hip contraction.

During the maximal combined hip contractions, the value representing the EMG amplitude recorded when the participant performed an MVC of the PFMs in combination with an MVC of the hip muscle was determined by taking the peak RMS amplitude recorded after the first footswitch had been triggered, indicating that the hip contraction had begun, and before the second footswitch trigger (indicating that the hip contraction had been broken).

**3.8.4 Crosstalk from the Transversus Abdominis**

For the abdominal hollowing task, cross-correlation functions were calculated using Matlab (v.2009) to determine the cross-correlation coefficient and time lag between peaks of the PFM and transversus abdominis EMG activity during each cycle of repeated transversus abdominis contractions. Additionally, the raw EMG data for each channel were plotted next to each other and inspected visually.

**3.9 Data Analyses**

Statistical Analyses were performed using IBM PASW Statistics (v.18), formerly SPSS Statistics, Matlab (v.2009), and Minitab (v.16). Analyses were always performed for both the right and left muscles.

**3.9.1 Between-trial Reliability**

Between-trial reliability was determined by calculating two different statistical measures: the intraclass correlation coefficient (ICC) and the coefficient of variation (CV). Both measures are important to consider when determining the between-trial reliability of a specific type of electrode during a certain task. ICC’s were calculated using Equation 1.
Because there were fixed electrode types being investigated, Model 3 was deemed to be appropriate for this study (Shrout & Fleiss, 1979). A single measurement is the unit of analysis, thus, ICC$_{(3,1)}$ is appropriate.

\[
\text{ICC}_{(3,1)} = \frac{\text{BMS} - \text{EMS}}{\text{BMS} + (k-1)\text{EMS}}
\]

(Equation 1)

where \( k \) represents the number of trials that were performed for each task, BMS is Between Subject Mean Square, and EMS is Error Mean Square.

Data from the right and left sides of the PFMs and right and left biceps were treated separately. Thus, the ICC for each electrode was calculated for the above tasks, for each side of the PFMs or biceps.

The CV is computed as the standard deviation of a data set (s), divided by the mean (\( \bar{x} \)), multiplied by 100 (See Equation 2). It is a measure of spread in the data.

\[
CV = \frac{s}{\bar{x}} \times 100\
\]

(Equation 2)

The CV was calculated for each muscle side (right or left) for each subject and task, and then average CV calculated for each task.

3.9.2 Between-day Reliability

Between-day reliability was determined by calculating the ICC and the mean absolute difference (MAD) between days for each electrode and task. Again, each side of the PFMs was analyzed separately.
For each of the PFM MVC, “catch a load”, and bicep MVC tasks, the average peak RMS amplitude was calculated across the three trials for each subject, thus an ICC(3,3) (Equation 3) was selected (Shrout and Fleiss, 1979).

$$ICC_{(3,3)} = \frac{BMS - EMS}{BMS}$$  
(Equation 3)

where BMS is Between Subject Mean Square, and EMS is Error Mean Square

Similar to the CV calculated for the between-trial reliability, the MAD was calculated in order to determine the variability of results between days. The MAD is the absolute difference between average peak activity of the three trials recorded during Session 1 and that recorded during Session 2 (Equation 4). The MAD was determined for each subject, with the right and left sides of the PFMs and biceps analyzed separately. An average MAD was then calculated for each task, and side of the pelvic floor or biceps. Standard deviations of the MAD were calculated for each electrode, task, and side of the muscle. Each subjects’ MADs was then normalized to their average activity during the two sessions (nMAD), in order to allow comparisons among the different electrodes (Equation 5). An average normalized MAD was then calculated for each task, and side of the pelvic floor or biceps.

$$MAD = |(Session 1 - Session 2)|$$  
(Equation 4)

where Session 1 indicates the mean RMS EMG amplitude recorded during session 1 and Session 2 indicates the mean RMS EMG amplitude recorded during session 2.
where \( \text{MAD} \) is the mean absolute difference between the values reported on Session 1 and Session 2, and Session 1 and 2 represent the average RMS amplitude recorded on Session 1 and 2, respectively.

The standard error of measurement (SEM; Equation 6) was calculated in order to determine the typical error associated with PFM EMG data recorded with the novel electrode and the Femiscan™ electrode, and the EMG activity recorded from the bicep using the Delsys™ electrode.

\[
\text{SEM} = \sqrt{\frac{SS_{\text{total}}}{(n-1)}} \times \sqrt{1-\text{ICC}}
\]  
(Equation 6)

where \( SS_{\text{total}} \) is the total variance in the sample, \( n \) is the sample size, and ICC is the intraclass correlation coefficient value, calculated using Equation 3.

In order to provide an idea of the difference in amplitudes that one must observe in order for that difference to be considered real, the minimal clinically important difference (MCID) was calculated, using Equation 7.

\[
\text{MCID} = \text{SEM} \times 1.96 \times \sqrt{2}
\]  
(Equation 7)

where \( \text{SEM} \) is the standard error of measurement, calculated according to Equation 6.

### 3.9.3 Motion Artifact

A t-test for proportions \((\alpha=0.05)\) was used to determine if there was difference in the prevalence of motion artifact recorded between the novel electrode and the Femiscan™.
3.9.4 Crosstalk from the Hip Adductors and External Rotators

As mentioned above, investigations pertaining to crosstalk from the hip musculature and the abdominals were handled differently. For the hip musculature, repeated measures analyses of variance (ANOVA) were performed in order to investigate differences in EMG amplitude recorded during hip contraction tasks, based on the type of vaginal electrode used, and the intensity of hip contraction performed. The significance level was set to $\alpha=0.05$. The interaction between contraction intensity and electrode type was included in the model.

For isolated hip muscle contractions (i.e. participants attempted to keep the PFMs relaxed) if the electrical activity recorded from the PFMs during the hip muscle contraction was significantly ($\alpha=0.05$) greater than the activity recorded from the PFMs when both the PFMs and the hip muscles were at rest, either crosstalk or co-activation may have occurred. In order to differentiate between crosstalk and co-activation, trends in performance for each vaginal electrode were descriptively compared. With the underlying assumption that subjects performed the tasks similarly with each vaginal electrode in situ (i.e. whether or not their PFMs tended to co-activate), any differences in the trends seen between the two different electrodes was likely due to crosstalk. As such, if, for example, one electrode recorded significantly higher EMG amplitudes during a 25% MVC hip contraction compared to what it recorded when the hip was relaxed, but the other electrode did not record any significantly different EMG amplitudes during the 25% MVC hip contraction, compared to what it recorded when the hip was relaxed, it is likely that the first electrode recorded crosstalk during this task. Similarly, if the peak RMS amplitude recorded during a combined contraction of the hip musculature and PFM MVC was statistically greater ($\alpha=0.05$) than the peak RMS amplitude generated during the isolated maximal PFM contraction without any hip muscle contraction, either crosstalk or PFM facilitation may have
occurred. Again if such an increase was seen when one electrode was used but not when the other one was used, this could be interpreted as the first electrode recording crosstalk.

The right and left sides of the PFMs were treated separately in order to elucidate whether crosstalk was an issue only during ipsilateral hip contractions, or whether contractions isolated to the contralateral leg also generated crosstalk.

### 3.9.5 Crosstalk from the Transversus Abdominis

Crosstalk was said to be likely to exist if (i) the bursts of transversus abdominis and PFM activity were near-synchronous (i.e. if the timing of the peak of the cross-correlation function ($\Delta$) between the transversus abdominis EMG signal and the PFM EMG signal $=0$) and (ii) if the bursts were highly correlated (i.e. if the cross-correlation coefficient ($r$) was close to one). This analysis was based on Marshall and Murphy (2003) who investigated the recording of crosstalk at the rectus abdominis from the internal and external obliques during voluntary contractions of the abdominal muscles. The timing between peaks of transversus abdominis and PFM activity should be near-synchronous if the vaginal electrodes were recording crosstalk since the electrical field generated by a nearby muscle is transmitted near instantaneously. Due to the sampling rate used for the recording fine wire EMG in this study (2000 Hz), the resolution of the time delay in the cross-correlation function should be equal to 0.5 milliseconds. As such, the time lag in the cross-correlation function was considered to be zero if it was less than 0.5 ms. On the other hand, if an electrode was recording crosstalk, while the muscle of interest is at rest, the correlation coefficient should be high. For the purposes of this research we assumed that a correlation coefficient of greater or equal to 0.90 indicated highly correlated bursts of muscle activity between the transversus abdominis and PFMs. Thus, crosstalk was said to exist if both the time
lag of the peak of the cross correlation function was less than 0.5 ms and if the peak of the cross-correlation coefficient was greater or equal to 0.90.

3.9.6 Acceptability of Vaginal Electrode Utilization

A non-parametric paired t-test (Wilcoxon sign-rank test, $\alpha=0.05$) was used to determine if there was significant difference in the acceptability of utilizing the novel electrode and Femiscan™. Separate t-tests were performed on acceptability ratings of physical comfort upon insertion and acceptability ratings of physical comfort during position changes.
Chapter 4

Results

4.1 Subjects

Twenty nulliparous women between the ages of 18 and 50 (26 ± 7 years) participated in the study. Height and weight measurements were used to calculate body mass index (BMI) for all subjects. The average BMI for the sample was 24.7 ± 9.3 kg/m². The average length of time between the first and second data collection sessions was 7 ± 2 days (range of 5 to 12 days).

Of the 20 subjects involved in the main study, 5 women participated in the optional portion of the study involving the investigation of crosstalk from the transversus abdominis. These women were between the ages of 22 and 40 (28 ± 7 years). The average BMI for this subset of the sample was 22.0 ± 3.7 kg/m².

4.2 Data Excluded from Analyses

Data were visually inspected to ensure that there was an easily detectable burst of EMG activity during tasks involving PFM or bicep contractions. All data from the “catch a load” task were excluded from the analysis due to the failure of this task to consistently evoke a clear, burst of EMG activity from the PFMs. Out of 222 files collected over both evaluation sessions, the novel electrode recorded a small response to the task in 13 files. Similarly, the Femiscan™ recorded a discernable response in 9 files. In the 22 files that recorded a PFM response to the task, determined through visual inspection, the response was subtle (average RMS amplitude: 23.6 µV; average signal to noise ratio: 14.8 decibels). As such, the between-trial and between-day
reliability of results recorded using this task could not be evaluated. Examples of data that included a small response to this task are displayed in Figures 4-1 and 4-2.

![Figure 4-1: Example of data recorded during the “catch a load” task using the Femiscan™, where the vertical pink line indicates the point in time when the load was dropped.](image)

![Figure 4-2: Example of data recorded during the “catch a load” task using the novel electrode, where the vertical pink line indicated the point in time when the load was dropped.](image)

EMG data were also excluded from the other analyses if clear bursts of EMG activity were not detected through visual inspection of the raw data in tasks involving contractions. Examples of data that were excluded are displayed in Figures 4-3 and 4-4.
Figure 4-3: Example of data contaminated with excessive noise

Figure 4-4: Example of data collected using the novel electrode during a PFM MVC. A minimal amount of muscle activity was recorded. Evidence of a sustained contraction is not present, and one is unable to clearly determine the onset of the contraction. This contraction is in contrast to the one presented in Figure 4-5. Motion artifact is also present between 1 and 1.5 seconds.

In 5 subjects, a clear signal was recorded from the left PFMs during the tasks investigating the effect of hip external rotation on the signal recorded from the PFMs (see Section 3.7.4.2), but the data were contaminated by 60 Hz noise. In these subjects, a 5th order band stop Bessel filter was applied between 57 and 63 Hz to data collected from the left PFMs with both the Femiscan™ and novel electrode during tasks involving hip external rotation. These filtered data were then included in the crosstalk analyses.
Table 4-1 displays the percentage of useable files that were recorded using each electrode, for each task. For the PFM EMG activity recorded using the Femiscan™ and the novel electrode, as well as the Delsys™ electrode recording biceps muscle activation, the average percentage of useable data files were 99.6%, 94.0%, and 85.0%, respectively. Data from the “catch a load” task are not represented in the table as no data were retained as discussed above.

For the reliability analyses (see Section 3.9.2), if a subject’s EMG data during an MVC was useable only on one of the two evaluation sessions, data from both sessions were excluded from the between-day reliability analysis. For the crosstalk from the hip musculature analyses (Section 3.9.4), if a subject’s EMG data was useable only for one vaginal electrode and not the other, that individual’s data were excluded from the analyses.

<table>
<thead>
<tr>
<th>Task</th>
<th>Femiscan™</th>
<th>Novel electrode</th>
<th>Delsys™ Electrode</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFM/Bicep MVC</td>
<td>100.0%</td>
<td>93.8%</td>
<td>85.0%</td>
</tr>
<tr>
<td>Hip adduction contractions</td>
<td>99.4%</td>
<td>93.8%</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Hip external rotation contractions</td>
<td>98.8%</td>
<td>88.5%</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Transversus abdominis contractions</td>
<td>100.0%</td>
<td>100.0%</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

Table 4-1: Percentage of useable files collected using each electrode

4.3 Between-trial Reliability

Raw data as well as peak RMS amplitudes recorded using each electrode were plotted and visually inspected prior to analysis. Examples of raw data recorded with each electrode are presented in Figures 4-5 to 4-7. Figure 4-8 represents the rectified and smoothed RMS amplitude values generated across all participants during the MVC task using each electrode. For the purposes of this figure, data from the right and left muscles were grouped together. In the ensuing statistical analysis, however, data from the right and left PFMs and right and left biceps were analyzed separately. Overall, the between-trial reliability of peak RMS amplitude recorded using
each electrode during an MVC was deemed excellent, as indicated by ICC values above 0.90 and low CV values, indicating low variability in the data sets. Table 4-2 summarizes the results of the statistical analyses.

Figure 4-5: Example of data collected during an MVC of the PFMs using the Novel electrode

Figure 4-6: Example of data collected during an MVC of the PFMs using the Femiscan™
Figure 4-7: Example of data collected during an MVC of the biceps using the Delsys™ electrode

Figure 4-8: Mean RMS amplitudes generated during the MVC task using each electrode, where 1, 2, and 3 represent repetition 1, 2, and 3 of the task. Error bars represent standard deviation.
### Table 4-2: Between-trial reliability of EMG data recorded using each electrode. The sample size represents the number of data sets used in each analysis.

<table>
<thead>
<tr>
<th>Task</th>
<th>Electrode</th>
<th>Side of muscle</th>
<th>Sample size (n)</th>
<th>ICC$_{(3,1)}$</th>
<th>CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MVC</td>
<td>Novel electrode</td>
<td>Right Left</td>
<td>20 18</td>
<td>0.964 0.974</td>
<td>8.6 8.8</td>
</tr>
<tr>
<td></td>
<td>Femiscan™</td>
<td>Right Left</td>
<td>20 20</td>
<td>0.943 0.974</td>
<td>11.2 11.2</td>
</tr>
<tr>
<td></td>
<td>Bicep Delsys™ electrode</td>
<td>Right Left</td>
<td>17 18</td>
<td>0.943 0.910</td>
<td>10.1 14.1</td>
</tr>
</tbody>
</table>

4.4 Between-Day Reliability

Average RMS amplitudes recorded using each electrode on each evaluation session were plotted and visually inspected prior to analysis. Table 4-3 displays the average RMS amplitude values generated during the MVC task using each electrode, on the first and second evaluation sessions. In the ensuing statistical analysis, data from the right and left PFMs and right and left biceps were analyzed separately. Overall, the between-day reliability calculated was variable, depending on electrode type and the side of the muscle being tested. Using Currier’s recommendations (1990) of reliability coefficient classification, the between-day reliability of the novel electrode ranged from poor to fair, depending on the side of the PFMs being tested, whereas the consistency of results across days using the Femiscan™ ranged from fair to excellent. When utilizing the Delsys™ electrode over the biceps muscle, reliability between days ranged from poor to good. The results of the statistical analyses are presented in Table 4-4.
Table 4-3: Mean (SD) RMS amplitudes recorded using the electrodes, on the first and second data collection sessions.

<table>
<thead>
<tr>
<th>Device</th>
<th>Side of muscle</th>
<th>Sample size (n)</th>
<th>RMS Amplitude Session 1 (µV)</th>
<th>RMS Amplitude Session 2 (µV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novel electrode</td>
<td>Right Left</td>
<td>18 18</td>
<td>32.4 (18.0) 39.1 (25.6)</td>
<td>33.1 (27.2) 30.5 (18.5)</td>
</tr>
<tr>
<td>Femiscan™</td>
<td>Right Left</td>
<td>20 20</td>
<td>38.9 (20.0) 47.3 (22.5)</td>
<td>45.2 (22.9) 41.9 (21.8)</td>
</tr>
<tr>
<td>Biceps Delsys electrode</td>
<td>Right Left</td>
<td>15 15</td>
<td>693.2 (416.7) 579.0 (369.1)</td>
<td>569.0 (384.9) 647.2 (401.3)</td>
</tr>
</tbody>
</table>

Table 4-4: Between day Reliability Results. Reported values are means with the standard deviation in parentheses. The number of data sets included in the analysis was the same as the sample sizes indicated in Table 4-3.

<table>
<thead>
<tr>
<th>Device</th>
<th>Side of muscle</th>
<th>ICC_{3,k}</th>
<th>MAD (µV)</th>
<th>nMAD (%)</th>
<th>SEM (µV)</th>
<th>MCID (µV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novel electrode</td>
<td>Right Left</td>
<td>0.715 0.648</td>
<td>14.9 (15.6) 19.4 (14.5)</td>
<td>45.5 67.0</td>
<td>17.5 18.7</td>
<td>48.5 52.0</td>
</tr>
<tr>
<td>Femiscan™</td>
<td>Right Left</td>
<td>0.788 0.924</td>
<td>14.1 (12.4) 9.5 (8.8)</td>
<td>38.8 21.5</td>
<td>14.1 8.8</td>
<td>39.2 24.5</td>
</tr>
<tr>
<td>Biceps Delsys electrode</td>
<td>Right Left</td>
<td>0.808 0.664</td>
<td>242.7 (235.9) 257.1 (260.7)</td>
<td>41.3 48.0</td>
<td>255.7 301.7</td>
<td>708.8 836.1</td>
</tr>
</tbody>
</table>

4.5 Prevalence of Motion Artifact Contamination Using Each Vaginal Electrode

The prevalence of motion artifact contamination during the coughing task was determined by analyzing power density spectra of each raw data file. Examples of raw data with and without motion artifact and the associated power density spectra are presented in Figures 4-9 to 4-12. In files deemed to contain motion artifact, the peak of the power in the 1 to 20 Hz range exceeded the mean power recorded in the 20-250 Hz range. Raw data from the right and left PFMs were analyzed separately, however, for the purposes of reporting motion artifact contamination, the right and left sides have been grouped together for each vaginal electrode.
Out of 354 files recorded during a cough using the novel electrode, 99 of those files were contaminated with motion artifact. Using the Femiscan™, 125 out of 390 files recorded during a cough were contaminated with motion artifact.

A t-test of proportions ($\alpha=0.05$) revealed no significant differences in the proportion of contaminated files recorded using each electrode ($p=0.225$).

![Figure 4- 9: Example of EMG data collected from the PFMs during a cough where the data were contaminated by motion artifact. The solid dark vertical lines indicate the one second window of data that were used in the power spectral density calculation.](image)

![Figure 4- 10: Power spectral density plot of the data in Figure 4-9. The 1 to 20 Hz range is located between the solid dark vertical lines.](image)
Figure 4-11: Example of data collected from the PFMs during a cough where the data are not contaminated by motion artifact. The solid dark vertical lines indicate the one second window of data that were used in the power spectral density calculation.

Figure 4-12: Power spectral density plot of data from Figure 4-11. The 1 to 20 Hz range is located between the solid dark vertical lines, where minimal signal power is present.

4.6 Crosstalk from the Hip Musculature

The presence of crosstalk in EMG recordings from the PFMs was evaluated using the results of the two-way repeated-measures ANOVA. An electrode by intensity interaction was found for the majority of tasks. This interaction was further analyzed using Tukey’s post hoc testing. It should be noted that tests for normality revealed that the data from this protocol were not normally distributed. Because a non-parametric equivalent to a two-way ANOVA that would
have allowed us to investigate possible electrode by intensity interactions does not exist, parametric statistics were still used.

4.6.1 Effect of Ipsilateral Hip Adductor Contractions

Average RMS amplitudes recorded from the right PFMs when the hip musculature was relaxed as well as during isolated hip adductor contractions are displayed in Figure 4-13. Average RMS amplitudes recorded from the right PFMs during a PFM MVC, as well as a combined PFM MVC and hip adductor contraction are displayed in Figure 4-14.

During a 25% and 50% MVC isolated right hip adductor contraction, the Femiscan™ recorded significantly higher EMG amplitudes (p=0.011 and 0.00001 for the 25% MVC and 50% MVC task, respectively) from the right PFMs compared to what it recorded when the hip muscles were relaxed whereas the novel electrode did not record any significant difference in EMG amplitude compared to what it recorded when the hip was relaxed (p=0.923 and 0.175 for the 25% MVC and 50% MVC task, respectively). Similarly, during a combined PFM MVC and 25% MVC of the right hip adductors, and a combined PFM MVC and 50% MVC of the right hip adductors the Femiscan™ recorded significantly higher EMG amplitudes (p=0.0001 and 0.00001 for the 25% MVC and 50% MVC hip adduction task, respectively) from the right PFMs compared to what it recorded when the hip was relaxed. The novel electrode did not record significantly different EMG amplitudes during the combined PFM MVC and 25% MVC or 50% MVC of the hip adductors compared to what it recorded when the hip was relaxed (p=0.122 and 0.2493 for the 25% MVC and 50% MVC hip adduction task, respectively).

During an isolated right hip adductor MVC, both the Femiscan™ and novel electrode recorded significantly higher EMG amplitudes compared to what each recorded when the hip was relaxed (p=0.00001 for both). This result was similar for the combined PFM and right hip
adductor contraction task, with both electrodes recording significantly higher EMG RMS amplitudes from the right PFMs during a concurrent right hip adductor MVC (p=0.00001 for both) compared to the amplitudes each recorded during a PFM MVC alone.

Figure 4-13: Average peak RMS amplitudes recorded from the right PFMs using each vaginal electrode during isolated right hip adduction tasks. Error bars represent standard deviation values. Asterisks indicate that there is a significant difference among tasks.
4.6.2 Effect of Contralateral Hip Adductor Contractions

Average peak RMS amplitudes recorded from the left PFMs when the hip musculature were relaxed as well as during the isolated right hip adductor contraction are displayed in Figure 4-15. Average EMG peak RMS amplitudes recorded from the left PFMs during a PFM MVC, as well as a combined PFM MVC and right hip adductor contraction are displayed in Figure 4-16.

During the isolated 25% MVC right hip adductor contractions, the Femiscan™ recorded significantly higher EMG peak RMS amplitudes from the left PFMs compared to what it recorded when the hip was relaxed (p=0.0001), whereas the novel electrode did not record any significantly different EMG amplitudes from the left PFMs compared to what it recorded when the hip was relaxed (p=0.367). During a combined PFM and 25% MVC right hip adductor contraction, however, both the Femiscan™ and novel electrode recorded significantly higher
EMG amplitudes from the left PFMs compared to what each recorded when the hip was relaxed (p=0.00001 and 0.005, respectively).

During the isolated 50% MVC right hip adductor contractions, both the Femiscan™ and novel electrode recorded significantly higher EMG amplitudes from the left PFMs compared to what each recorded at rest (p=0.00001 and 0.01, respectively). Similarly, during a combined PFM MVC and right hip adductor 50% MVC contraction, both vaginal electrodes recorded significantly higher EMG amplitudes from the left PFMs compared to what each recorded during an isolated PFM MVC (p=0.00001 for the Femiscan™, p=0.004 for the novel electrode).

During the isolated MVC of the contralateral hip adductors, both the Femiscan™ and novel electrode recorded significantly higher EMG amplitudes from the PFMs compared to what each recorded at rest (p=0.00001 for both). Similarly, both electrodes recorded significantly higher EMG amplitudes during a PFM MVC and concurrent contralateral hip adductor MVC compared to a PFM MVC performed alone (p=0.00001 for both).
Figure 4-15: Average peak EMG RMS amplitudes recorded from the left PFMs using each vaginal electrode during isolated right hip adduction tasks. Error bars represent standard deviation values. Asterisks indicate a significant difference among tasks.

Figure 4-16: Average peak EMG RMS amplitudes recorded from the left PFMs using each vaginal electrode during an isolated PFM MVC, as well as concurrent right hip adduction at increasing intensities. Error bars represent standard deviation values. Asterisks indicate a significant difference among tasks.
4.6.3 Effect of Ipsilateral Hip External Rotator Contractions

Average peak EMG RMS amplitudes recorded from the right PFMs when the hip musculature was relaxed as well as during isolated right hip external rotator contractions are displayed in Figure 4-17. Average RMS amplitudes recorded from the right PFMs during a PFM MVC, as well as combined PFM MVC and right hip external rotator contractions are displayed in Figure 4-18.

During isolated 25% MVC right hip external rotator contractions, the Femiscan™ recorded significantly higher EMG amplitudes from the right PFMs compared to what it recorded when the hip was relaxed (p=0.055), however, the novel electrode did not record significantly different amplitudes compared to what it recorded at rest (p=1.000). Similar results were found using data from the second stream of tasks, i.e. combined PFM MVC and right hip external rotation. The Femiscan™ recorded significantly higher EMG RMS amplitudes from the right PFMs during a PFM MVC with a concurrent 25% MVC right hip external rotator contraction compared to what it recorded during a PFM MVC alone (p=0.002), whereas the novel electrode did not record significantly different amplitudes during the task compared to what it recorded during a PFM MVC alone (p=0.992).

During the isolated 50% MVC of the right hip external rotators, the Femiscan™ recorded significantly higher EMG amplitudes from the right PFMs compared to rest values (p=0.00001). This was not the case with the novel electrode (p=0.671). During the second stream of tasks at this intensity, both the Femiscan™ and novel electrode recorded significantly higher EMG amplitudes from the right PFMs during the PFM MVC with concurrent right hip external rotator contraction compared to what each recorded during a PFM MVC alone (p=0.00001, 0.004 respectively).
Both streams of tasks at the level of maximal effort right hip external rotator contraction revealed significantly higher RMS amplitudes recorded from the right PFMs by each vaginal electrode compared to what each recorded when the hip remained relaxed (p=0.00001 for both electrodes in both streams of tasks).

Figure 4-17: Average Peak EMG RMS amplitudes recorded from the right PFMs using each vaginal electrode during isolated right hip external rotation tasks. Error bars represent standard deviation values. Asterisks indicate a significant difference among the tasks.
Figure 4-18: Average peak EMG RMS amplitudes recorded from the right PFMs using each vaginal electrode during a PFM MVC and concurrent right hip external rotation. Error bars represent standard deviation values. Asterisks indicate a significant difference among tasks.

4.6.4 Effect of Contralateral Hip External Rotator Contractions

Average peak EMG RMS amplitudes recorded from the left PFMs when the hip musculature was relaxed as well as during isolated right hip external rotator contractions are displayed in Figure 4-19. Average peak EMG RMS amplitudes recorded from the left PFMs during a PFM MVC, as well as combined PFM MVC and right hip external rotator contractions are displayed in Figure 4-20.

At 25% MVC of contralateral hip external rotation, neither the Femiscan™ nor the novel electrode recorded any significantly different EMG amplitudes from the left PFMs during an isolated right hip external rotator contraction compared to what each recorded when the hip was relaxed (p=1.000 for both).
During the 50% MVC isolated right hip external rotator contraction, the Femiscan™ recorded significantly higher EMG amplitudes from the left PFMs compared to what it recorded when the hip was relaxed (p=0.0001), whereas the novel electrode did not record significantly different EMG amplitudes from the left PFMs compared to what it recorded at rest (p=0.291).

During an isolated MVC of the right hip external rotators, both the Femiscan™ and novel electrode recorded significantly greater EMG amplitudes from the left PFMs compared to what each recorded when the hip remained relaxed (p=0.00001 for both).

In this case the ANOVA for EMG data recorded from the left PFMs during the combined PFM MVC and right hip external rotation contraction tasks revealed an electrode main effect and an intensity of contraction main effect (p=0.00001 for both) but no electrode by intensity of hip contraction interaction (p=0.338). Although EMG amplitudes recorded from the left PFMs during the 25% MVC, 50% MVC, and MVC tasks were significantly greater than amplitudes recorded when the hip was relaxed (p=0.01, p=0.002, p=0.00001 respectively) and the EMG amplitude recorded during the 25% MVC and 50% MVC tasks were significantly different from the amplitude recorded during the MVC task (p=0.00001 for both), no difference in trends existed between the two vaginal electrodes.
Figure 4-19: Average Peak EMG RMS amplitudes recorded from the left PFMs using each vaginal electrode during isolated right hip external rotation tasks. Error bars represent standard deviation values. Asterisks indicate a significant difference among tasks.

Figure 4-20: Average Peak EMG RMS amplitudes recorded from the left PFMs using each vaginal electrode during a PFM MVC and concurrent right hip external rotation. Error bars represent standard deviation values. Asterisks indicate a significant difference among tasks.
4.7 Crosstalk from the Transversus Abdominis

Although five subjects participated in the additional crosstalk protocol, data from two subjects were not used due to incomplete data sets: the fine wires in the transversus abdominis dislodged during testing in one participant and in the other, signal contamination was present during a transversus abdominis MVC. Because of this signal contamination, we could not use the MVC data for normalization, nor to present the relative signal amplitude to the participant during the subsequent tasks. In one of the three remaining participants, the fine wires were placed inside of the internal oblique muscle instead of the transversus abdominis, as the origin of this subject’s transversus abdominis was located very lateral on the abdominal wall and therefore was not situated near the anterior pelvis (This was verified through ultrasound imagining). In this participant, crosstalk from the internal oblique muscles was likely a much higher risk to the PFM EMG recordings than it was from the transverses abdominis muscle. Therefore, instead of performing the abdominal hollowing maneuver, this subject performed ipsilateral trunk rotation against a manual resistance supplied by the investigator. Data collected from this subject were included in the analysis. Figure 4-21 displays an example of the filtered EMG data collected from the transversus abdominis and PFMs during an abdominal hollowing maneuver (See Appendix 7.8 to 7.10 for graphs of filtered data collected from each participant, at each abdominal muscle contraction intensity, and with each vaginal electrode). For both vaginal electrodes, the cross-correlation coefficients between the abdominal and PFMs were less than 0.90 and the associated time lags were greater or equal to 0.5 milliseconds, suggesting that crosstalk between the deep abdominals and PFMs was not a concern. Table 4-5 summarizes the results of the analyses, where values reported for each subject are the average of the absolute values of time lags and reliability.
coefficients calculated using three repetitions for each participant.

Figure 4- 21: EMG data recorded during a 50% MVC of the transversus abdominis muscle. A) presents transversus abdominis EMG activity and B) presents simultaneous PFM activity, recorded using the Femiscan™.
Table 4-5: Average peak correlation coefficients (r) and time lags (\(\Delta\)) between PFM activity and transversus abdominis activity recorded during three trials of each task for each subject. The asterisk indicates the subject in which fine wires were placed in the internal oblique muscle.

### 4.8 Acceptability of Use

It was significantly more acceptable to change position with the novel electrode in situ than the Femiscan™ (Wilcoxon test, \(p=0.035\)), however, there was no significant difference in acceptability of vaginal electrode insertion. The average response regarding acceptability of insertion of the both the novel electrode and Femiscan™ was 2 ±2 out of 10. The average response regarding acceptability of position changes with the novel electrode in place was 2 ±2 out of 10. It was less acceptable to change positions with the Femiscan™ in situ, indicated by an average response of 3 ±2 out of 10 for this electrode.
Chapter 5

Discussion

5.1 Summary of Results

Overall, the between-trial reliability of the novel electrode was excellent, as was the reliability of recording EMG amplitude with the Femiscan™ and the Delsys™ electrode over the biceps muscle. Reliability was less consistent between days as indicated by lower ICC value classifications (Currier, 1990), especially for the novel electrode and bicep Delsys™ electrode. The novel electrode was unsuccessful in reducing motion artifact during a cough, but a difference in electrode performance during contractions of the hip musculature at submaximal intensities, especially during ipsilateral hip muscle contractions was seen, suggesting that the novel electrode is less likely to record crosstalk from the hip musculature than the Femiscan™. Crosstalk from the transversus abdominis did not appear to be a problem with either the Femiscan™ or the novel electrode as the peak correlation coefficients and time lags between bursts of PFM activity and transversus abdominis activity were less than $r=0.90$ and greater than $\Delta = 0.5$ ms. It was significantly more acceptable to change position with the novel electrode in situ compared to the Femiscan™, however, both vaginal electrodes were equally acceptable upon insertion.

5.2 Participant Characteristics

Participants in this study were nulliparous women between 18 and 50 years old, with no history of PFM dysfunction. This target population was chosen in order to study the psychometric properties of the novel electrode, while minimizing potential confounders, such as inconsistency in the performance of PFM contractions, or due to orthopedic or neuromuscular damage to the PFMs. As such, the results of this study may not be reproducible in parous or
older women, or in women with incontinence, prolapse, or sexual pain disorders. If results did
differ in other populations, however, these differences are unlikely to be a reflection of the
psychometric properties of the novel electrode itself, but may be due to inconsistencies in
performance in women with PFM dysfunction (Allen, Hosker, Smith, & Warrell, 1990; Bo et al.,
1988).

5.3 Between-trial Reliability of EMG amplitude recorded during an MVC task

Within each evaluation session, both the vaginal electrodes and bicep Delsys™ electrode
remained in situ. As such, each electrode should have recorded EMG activity from the same
motor units located within its pick-up area during each repetition of the MVC task. Provided that
the position of the electrodes relative to the active motor units did not change between repetitions
and that subject performance remained comparable, one would expect the between-trial reliability
of EMG amplitude recorded during the task to be high using all electrodes. In fact, all electrodes
did show excellent reliability of results recorded during the same session, indicated by ICC(3,1)
values between 0.910 and 0.974 and low CV values (between 8.6 and 14.1%). This result was not
surprising, given that within a session, the location of the electrodes was not altered once each
electrode was appropriately positioned. Furthermore, each participant attended a familiarization
session prior to the evaluation sessions to minimize the training effect and thus maximize
consistency in performance.

Our results are consistent with the few studies that have investigated the psychometric
properties of the Femiscan™. Grape et al. (2009) reported that the between-trial reliability of
peak EMG amplitude recorded during an MVC using the Femiscan™ was excellent (ICC(3,1) =
0.90, CV = 14.3%). Similarly, Aukee et al. (2002) reported high consistency of results using data
collected during the second and third repetition of a short ‘flick’ contraction, with a Sspearman’s
correlation coefficient value of 0.92 (p=0.001). The between-trial reliability of peak PFM EMG amplitude recorded using the Femiscan™ was somewhat more variable in the study by Auchincloss & McLean (2009b), with ICC(3,1)’s ranging from 0.72 to 0.98, and CV values ranging from 8.5 to 14.2 percent. Thus, using Currier’s recommendations (1990), the reliability reported in Auchincloss & McLean’s (2009b) study ranged from fair to excellent. In Auchincloss & McLean’s study (2009b), the ICC’s and CV’s were calculated on both the first and second evaluation sessions. Less consistent reliability between trials was found during the first evaluation session (ICC(3,1) = 0.72 to 0.89) compared to the second evaluation session (ICC(3,1) = 0.96 to 0.98). Auchincloss & McLean (2009b) did not include a training session prior to the data collection sessions, as was done in the current study to minimize differences due to the training effect. If one looks at the between-trial reliability of data collected from the second evaluation session in Auchincloss & McLean’s (2009b) study, the results are quite comparable to that of the current study. These results suggest that EMG data recorded using the Femiscan™ probe are more reliable when the subjects are familiarized with the task prior to recording the data to be used in the analysis. Grape et al. (2009) also familiarized subjects with a PFM contraction during an appointment conducted prior to their evaluation sessions, supporting the contention that a familiarization session increases the reliability of results recorded with the Femiscan™.

To date, only one study (Gabriel, 2000) has investigated the between-trial reliability of recording EMG from the biceps brachii muscles, and this study showed high between-trial reliability (ICC = 0.93). Although the results of the Gabriel’s study are similar to the results of the current study, he did not investigate the reliability of EMG recordings during an MVC task, but rather a task that involved rapid elbow flexion from full extension to 90 degrees of flexion without resistance. Between-trial reliability of recording EMG amplitude from other peripheral
muscles has been investigated, although sparsely, and is consistent with the results from the current study. Fauth et al. (2010) investigated the between-trial reliability of recording EMG amplitude from the all portions of the quadriceps and hamstrings muscles in 24 subjects (both male and female) during isometric MVCs of the appropriate muscle. The between-trial reliability was reported to be excellent for each of the 6 individual muscles studied (ICC = 0.94 -0.97, CV = 11.5 -21.9%). Dankaerts et al. (2004) studied the between-trial reliability of recording EMG from the abdominal muscles (rectus abdominis, and internal and external obliques) and found good to high reliability (ICC=0.84 to 0.98) of EMG amplitude recorded in six healthy subjects who performed an MVC task against manual isometric resistance. Danneels et al. (2002) also found high reliability of EMG amplitude when recording from the multifidus and iliocostalis lumborum muscles during the appropriate MVC task (ICC = 0.94 to 0.98) in 77 healthy subjects. Thus, the results of the current study agree with those reported in similar studies investigating different muscle groups.

5.4 Between-day Reliability of EMG amplitude recorded during an MVC task

If one were to position an EMG electrode, and then remove and replace that same electrode, it is expected that variation in the location of the detection surfaces relative to the active motor units would be present upon re-application, altering the EMG amplitude recorded. Between days, differences in subject performance, tissue hydration, and motor unit activation may also exist. For this reason, one would expect the consistency of results between days to be worse than the consistency of results between trials. In the current study, this was the case, where the between-day reliability of EMG amplitude for each electrode was significantly worse than its between-trial reliability (p<0.005 using Wilcoxon sign-rank test).
The between-day reliability of the Femiscan™ fell within the fair to excellent range based on Currier’s (1990) recommendations (ICC’s between 0.788 and 0.924), whereas the novel electrode fell within the poor to fair range and the bicep Delsys™ electrode fell within the poor to good range. It therefore appears that the Femiscan™ electrode outperforms the others in terms of between-day reliability.

5.4.1 Effect of Electrode size

The result that the Femiscan™ demonstrated higher between-day reliability than the other two electrodes tested in this study is not unexpected. Large electrode surfaces, such as those featured on the Femiscan™ have a larger pick-up area and record activity from a greater number of motor units than smaller electrodes (De Luca, 1997). Because more motor units are contributing to the resultant EMG signal (De Luca, 1997), it stands to reason that the large electrodes will be less reliant on recording from all of the exact same motor units on different days. Slight variations in electrode placement or in motor unit activation from day to day presumably have less of an impact on the EMG signal amplitude recorded by large electrodes compared to small electrodes. On the other hand, devices that feature small electrode surfaces, such as those positioned on the novel electrode, have a small pick-up area and will record activity from a small number of motor units (De Luca, 1997) and thus, the resultant EMG signal is more specific to a small number of motor units. Variations in the location of small electrodes with respect to the active motor units, as well as in motor unit activation from day to day are more likely to impact the EMG signal amplitude, resulting in decreased consistency of results between days. In accordance with this discussion, the current study found that the ranking of the best to worst between-day reliability of the three electrodes studied (according to Currier’s (1990) recommendations) corresponded to the ranking of largest to smallest electrode surface area.
When grouping the ICC value for the right and left sides of the muscles together, the mean ICC\(_{(3,1)}\) values for the Femiscan\(^\text{TM}\), bicep Delsys\(^\text{TM}\) electrode, and novel electrode were ICC\(_{(3,1)}\) = 0.856, 0.736, and 0.682, respectively. The surface area covered by each detection surface on the Femiscan\(^\text{TM}\), Delsys\(^\text{TM}\) electrode, and novel electrode are 17.5 mm\(^2\), 10.0 mm\(^2\), and 1.0 mm\(^2\), respectively. Thus, between-day reliability did indeed correspond to electrode size. Consistent with this discussion, Auchincloss & McLean (2009b) tested the reliability of the Femiscan\(^\text{TM}\) relative to an intravaginal probe that featured even larger electrodes (the Periform\(^\text{TM}\)) and found better consistency of results using the Periform\(^\text{TM}\), with ICC\(_{(3,1)}\) values of 0.79 to 0.89, whereas the ICC\(_{(3,1)}\) values using data collected using the Femiscan\(^\text{TM}\) were 0.63 to 0.79.

**5.4.2 Effect of proprioceptive feedback**

Another factor that should be taken into account is the possibility of varying proprioceptive feedback provided by each vaginal device. In the current study, most subjects reported that they could not feel the novel electrodes inside the vaginal canal after they were inserted. On the other hand, subjects reported that they were aware of the Femiscan\(^\text{TM}\) throughout testing, some commenting that they could “feel the contraction better” during the MVC task when the Femiscan\(^\text{TM}\) probe was in situ. Although no studies to date have investigated the number of muscle spindles found within the PFMs, it is a general observation in our laboratory that women seem to lack a sense of proprioception regarding PFM contractility in comparison to other skeletal muscles. Thus, the presence of a large device inside the vaginal canal may have provided women with increased proprioception which may, in turn, have increased consistency in performance between days.
5.4.3 Differences in Reliability between Right and Left Sides

In the current study, reliability metrics of EMG amplitude recorded between days was poorer when recording activity from the left PFMs (ICC\(_{(3,1)} = 0.648\); poor reliability) compared to recording activity from the right PFMs (ICC\(_{(3,1)} = 0.715\); fair reliability) using the novel electrode. Lower reliability on the left side may have been caused by two issues. First, the investigator who inserted the novel electrodes was right-hand dominant. Due to the method in which the electrodes were inserted, it was easiest for the investigator to utilize her right index finger to position the novel electrode against the right PFMs, and to utilize her left index finger to position the novel electrode against the left PFMs. Thus, decreased consistency of EMG amplitude between days when recording from the left PFMs may have been due to poorer consistency in electrode placement when positioned with the investigator’s non-dominant hand. Inconsistencies in results due to handedness have been previously reported in the literature. Intranal electrical stimulation is performed using a St. Mark’s electrode, which is a small electrode that is usually glued and mounted onto the index finger of a gloved hand. An investigator positions the tip of their index finger inside the rectum, facing posterior and laterally, such that electrical stimulation can depolarize the pudental nerve. Lefaucheur, Yiou, & Thomas (2001) investigated pudental nerve terminal motor latencies in healthy men using the St. Mark’s electrode, as well as a novel electrode that did not require intranal insertion using an index finger. When using the St. Mark’s electrode positioned on the investigator’s right index finger, a significant (p<0.05) difference was found between right and left latencies, whereas when using the novel electrode that did not require intranal palpation, no significant difference between right and left pudental nerve latencies was found.
Variation in the positioning of the novel electrode over the left PFMs may also have affected reliability because the left novel electrode was always positioned after the right novel electrode was already suctioned onto the right vaginal canal. More care was required during the insertion of the second electrode in order to avoid dislodging the first electrode, which increased difficulty associated with positioning the second electrode in the proper position over the pubococcygeus muscle. More error may have been associated with positioning the electrode over the left PFMs while attempting to avoid dislodging the electrode already adhered to the right vaginal wall, which may have resulted in lower signal reliability between days compared to the right PFMs. Variation in the positioning of the novel electrodes are a likely cause of the overall decreased consistency associated with using the novel electrode between days, as it is not possible to landmark the attachment site of the novel electrode as was done for the electrodes placed over the biceps muscle, where the location of the electrode was measured based on anatomical landmarks in order to facilitate the reproduction of the electrode placement from day to day. The Femiscan™ probe, in contrast, needs no landmarks to ensure that the position is consistent from one insertion to the next. The probe is inserted into the vagina as far as possible given the geometric properties of the probe, where an external portion is seated against the caudal aspect of the pubis to prevent further penetration. This depth of insertion is easily replicated from one insertion to the next.

It should be noted that the Delsys™ electrode located over the biceps brachii muscle also produced lower reliability on the left side than on the right side. Obviously these difficulties in consistent placement of the electrodes are not an issue in this case. Instead, the discrepancy in reliability when recording EMG from the bicep may have been due to variable subject performance between days when utilizing their non-dominant hand. Although no data were
collected in the present study regarding handedness, it is likely the majority of our subjects were right-handed (Peters, Reimers, & Manning, 2006). It is possible that subjects were less consistent in performance across days when utilizing their non-dominant hand, however, this possible discrepancy has never been studied, and thus cannot be substantiated. In the few studies that investigated the reliability of assessing bicep muscle function, none compared the reliability of the data between the right and left sides.

Side to side differences in reliability measures were only noted for the ICC values, not for the MAD or nMAD values.

**5.4.4 Between-day Reliability Metrics**

No other studies have investigated the reliability of recording EMG amplitude from the biceps brachii between days, using the same task or data processing approaches as the present study, thus, comparisons to the literature cannot be made.

Only two other studies have investigated the between-day reliability of EMG amplitude recorded using the Femiscan™. Grape et al. (2009) tested the between-day reliability of peak EMG amplitudes recorded using the Femiscan™ during a PFM MVC, in 15 healthy subjects evaluated 26 to 30 days apart. Although the right and left PFMs were evaluated separately, the reported ICC(2,1) (ICC= 0.90) was the mean of the ICC values from the right and left sides. The average ICC values from the current study, when we group the right and left PFMs together as was done by Grape et al. (2009), was ICC(3,1) = 0.86. Thus, the results of the current study are in general agreement with Grape et al. (2009). On the other hand, Auchincloss & McLean (2009b) investigated the between-day reliability of EMG amplitude recorded using the Femiscan™ during a supine MVC task, and reported lower reliability metrics. ICC(3,1) values ranged from 0.63 to 0.79, thus, reliability was classified as poor to fair. It is interesting to note that we used the same
electrode configuration as Auchincloss & McLean (2009b) however we found the reliability to be higher according to ICC value classification. The discrepancy in results is unlikely to be due to differences between samples in the two studies, since both studies employed young, healthy asymptomatic women. As mentioned above, Auchincloss and McLean (2009b) did not include a training session prior to their data collection sessions as was done by Grape et al. (2009) and in the current study, which may have resulted in a learning effect influencing performance and thus decreasing consistency in results between days. Furthermore, Auchincloss & McLean (2009) used a sample size (n = 10) that was smaller than that used in either Grape et al. (2009)’s study or in the present study. Thus, perhaps the reliability of EMG amplitude recorded between days would have been more consistent with the current study if a larger sample had been used.

It is important to note that although there is a discrepancy in the between-day reliability reported between the current study and Auchincloss & McLean’s (2009b) when using ICC’s to classify the reliability (Currier, 1990) of data recorded using the Femiscan™, no such discrepancy exists when comparing other reliability metrics such as the SEM, MAD and nMAD. The current study found the SEM associated with using the Femiscan™ to be 8.8 to 14.1 µV, the MAD to be 9.5 to 14.1 µV, and the nMAD to range from 21.5 to 38.8% of the mean EMG amplitude recorded. Auchincloss & McLean found similar results (SEM = 10.1-15.1 µV, MAD = 9.9-16.1 µV, nMAD = 26.0-32.2%). This disappearance of the discrepancy in study results highlights the inherent drawback in the utilization of ICC values: the ICC is strongly driven by the heterogeneity of the sample, meaning that a sample that has a large amount of variability between subjects will produce results that appear to be more reliable. For this reason, ICCs should not be used in isolation as measures of repeatability. Instead it should be used combination with other reliability metrics such as the MAD, nMAD, and SEM.
In the current study, MAD values ranged from 9.5 to 257.1 µV, and nMAD values ranged from 21.5 to 67.0 percent across all electrodes studied. Although no standards regarding interpretation of these other reliability metrics exist, it is apparent that the large nMAD values computed indicate a lack of consistency in the EMG amplitude recorded from day to day, for all electrodes tested.

Furthermore, based on the large SEM and MCIDs associated with using the Femiscan™, the novel vaginal electrode, and the Delsys™ electrode placed over the biceps muscle (MCID = 24.5-39.2 µV, 48.5-52.0 µV, and 708.8-836.1 µV, respectively), the findings of the current study suggest that the application of EMG in investigating changes in muscle activation across time (for example, in response to treatment) is limited.

5.5 Between-trial and between-day reliability recorded from the PFM during the “Catch a load” task

It is interesting that neither the Femiscan™ nor the novel electrode recorded a consistent response of the PFM during the “catch a load” task, although the same protocol (including load mass and drop height) was used as described by Smith et al. (2007) and Capson et al. (2010). In both studies a larger Periform™ electrode was used. These larger electrodes may have had the capacity to record larger EMG signals than the Femiscan™ or novel electrode used in the current study. It is also possible that these electrodes recorded activity from the superficial PFM instead of or in addition to the deep PFM (Voorham-Van Der Zalm et al., 2006). In Smith et al.’s study, the response of the PFM to the loading task was investigated in both 14 continent and 16 incontinent women. Smith et al. (2007) performed an extra protocol in which they investigated the effect of obliquus internus abdominis, rectus abdominis, rectus femoris, hip adductor, gluteal, and hamstring muscle contractions on the signal recorded from the PFM. The authors provided
a sample of raw EMG data obtained simultaneously from the PFMs and the nearby muscles listed above during contractions of the latter, in which the PFMs do not demonstrate any obvious crosstalk. This protocol was, however, only performed by one continent subject, thus the results cannot prove that crosstalk was not an issue for all subjects who participated in the main study.

Regardless, there was no consistent EMG response recorded during the “catch a load” task used in the current study, and thus the reliability of the EMG response amplitudes were not assessed. In a future study, perhaps a larger load should be used, or the load should be dropped from a higher height.

5.6 Motion Artifact

Contrary to our hypothesis, the novel electrode was not successful in decreasing the prevalence of motion artifact contamination in EMG data recorded from the PFMs during the coughing tasks. Intravaginal probes are prone to motion artifact due to the sliding of the probe caudally as a result of the downward forces created by the abrupt increase in intra-abdominal pressure during this task. Although the design of the novel electrode prevents movement of the detection surfaces relative to the vaginal wall, one must remember that during a cough, the PFMs may move cranially (Hugosson, 1991) in a rapid manner. Thus, although the electrodes are adhered to the vaginal wall, the PFMs move relative to the vaginal wall and this movement could still result in motion artifact being recorded by the novel electrode.

The prevalence of motion artifact contamination in EMG data recorded using intravaginal probes is rarely reported in the literature. Auchincloss & McLean (2009b) reported that 36 out of 240 coughing trials were contaminated with motion artifact when using the Femiscan™. In the current study, the prevalence of motion artifact in EMG data was found to be much higher, likely because Auchincloss & McLean asked subjects to repeat the coughing task while holding the
probe in place whenever motion artifact was identified during testing (Brown, 2007) in order to minimize data contamination. Given that the current study and Auchincloss & McLean’s (2009b) study has demonstrated that motion artifact contamination when recording EMG amplitude from the PFMs is an issue, even when steps to minimize this contamination are actively taken, it is worrisome that the presence of motion artifact contamination is rarely reported in the literature. It is quite possible that others are not checking their data carefully enough, and that data contaminated with motion artifact are being included in the analysis, threatening the validity of results obtained.

5.7 Crosstalk from the Hip Musculature

There were significant increases in PFM EMG RMS amplitudes using both electrodes as the level of the hip muscle contraction force increased. Such increases in PFM EMG may have been due either to crosstalk or to co-activation of the PFMs in response to the task demands for stabilization of the pelvis (Hodges, Sapsford, & Pengel, 2007). If the electrodes demonstrated similar increases in EMG activation amplitude with the hip muscle contractions, it would not be possible to distinguish between crosstalk and co-activation using this method. In general, the electrodes did not, however, demonstrate consistent patterns in PFM EMG activation amplitude across increases in hip muscle activation. For instance, the Femiscan™ recorded significantly higher EMG amplitudes during a 25 percent of MVC hip adduction contraction compared to what it recorded when the hip was relaxed, but the novel electrode did not record any significantly different EMG amplitudes during the hip contraction, compared to what it recorded when the hip was relaxed. Because of this difference between electrodes, if we assume that the participant performed the task consistently with both electrodes in situ, it is likely that the Femiscan™ recorded crosstalk during the 25% MVC hip adduction contraction since the data recorded by the
novel electrode suggest that no co-activation occurred. A limitation of this method is that one cannot draw definitive conclusions about the presence of crosstalk in EMG recordings when both vaginal electrodes recorded significantly higher RMS amplitudes during increased activation of the hip muscles. For this reason, two streams of tasks were investigated in the current study – in the first, participants attempted to keep their PFMs relaxed while working their hip muscles at increasing intensities of contraction and in the second, participants attempted to maximally contract their PFMs while working their hip muscles at increasing intensities of contraction. The rationale for including two streams of tasks was to elucidate differences between crosstalk and co-activation in one task if we were unable to distinguish between them during the other task.

5.7.1 Crosstalk from the Hip Adductors

On the ipsilateral side at the 25 percent and 50 percent hip adductor contraction level, the Femiscan™ recorded significantly higher RMS amplitudes compared to what it recorded when the hip was relaxed, whereas the novel electrode did not. This result was consistent for both streams of tasks. Taken together, these results suggest that the Femiscan™ electrode recorded crosstalk from the hip adductors during ipsilateral 25% MVC and 50% MVC contractions. Once the contraction intensity reached the MVC level, both the Femiscan™ and the novel electrode recorded significantly higher EMG amplitudes compared to what each recorded when the hip was relaxed. It is interesting to note that both vaginal electrodes recorded significant increases in PFM EMG at the MVC level of hip muscle contractions, regardless of the side of PFMs being studied or the hip muscle being activated. This is likely because the PFMs are considered core stabilizers of the spine (Hodges, Sapsford, & Pengel, 2007). Thus, given the relative instability generating an ipsilateral maximal force at the hip musculature imposes on the pelvis, it is highly plausible that the PFMs may co-activate in order to maintain pelvic stability. Regardless, because both
vaginal electrodes recorded significantly higher RMS amplitudes during a maximal effort contraction of the hip adductors during both streams of tasks, we cannot draw any conclusions regarding the superiority of one electrode over the other in terms of recording crosstalk during hip adductor contractions at levels above 50% MVC. Similar results were found on the contralateral side during isolated hip adductor contractions; however both vaginal electrodes recorded increases in PFM EMG activation by the time the contralateral hip adductors reached a 50% MVC.

Although participants were instructed to perform the hip adductor contractions with their right side while keeping their left hip adductors relaxed, in reality it is difficult to do this. The participant’s position was selected to facilitate relaxation of the contralateral hip adductors during the task, however we did not monitor the contralateral hip adductors to ensure that they remained relaxed throughout the task. As such, the increases in PFM EMG activation seen at MVC on the ipsilateral side and by 50% MVC on the contralateral side may be related to crosstalk from the contralateral hip adductors, due to co-activation of the PFMs, or due to crosstalk from other muscles in the hip girdle which were co-activated to assist with stabilizing the hip and trunk during the task.

5.7.2 Crosstalk from the Hip External Rotators

Similarly, while the PFMs remained relaxed, the Femiscan™ appears to have recorded crosstalk from the ipsilateral hip external rotators at contraction intensities of 25 and 50% MVC whereas the novel electrode did not. This result was not consistent during the second stream of tasks, where both electrodes recorded significantly higher EMG amplitudes during the 50% MVC ipsilateral hip external rotation task compared to what each recorded when the hip was relaxed, suggesting that the ipsilateral hip external rotation contraction may have facilitated the PFM
MVC. Because the obturator internus fascia provides an attachment site for the PFMs (Schunke et al., 2006), it is thought that an obturator internus contraction will pull on the PFMs via the obturator internus fascia and provide them with a stretch stimulus, facilitating a contraction of the deep PFMs (Spitznagle, 2006). Although facilitation of a PFM contraction via the obturator internus has not been directly investigated as of yet, the use of a hip external rotation contraction in facilitating a PFM contraction is being used as a treatment strategy (Parekh et al., 2003). Thus, the results of the current study suggest that when using hip muscle contractions to facilitate a PFM contraction, concurrent ipsilateral hip external rotation at 50 percent of maximal effort may be effective in producing a significant increase in PFM activity.

On the contralateral side, the results were similar except that neither electrode appeared to record crosstalk during the 25% MVC isolated hip external rotation contraction. The results of the first stream of tasks could not be supported by the results of the second stream of tasks involving combined hip and PFM contractions, as no electrode by intensity interaction was found, indicating that there was no difference in the behavior of each electrode during the various hip external rotation tasks. Because the electrodes demonstrated similar increases in EMG activation amplitude with the hip muscle contractions, it was not possible to distinguish between crosstalk or co-activation using our methods, elucidating the inherent difficulty in differentiating between crosstalk and co-activation.

### 5.7.3 Influence of Vaginal Electrode Geometry on Crosstalk Results

As previously noted, most subjects were unable to feel the presence of anything inside the vaginal canal during testing with the novel electrode in place but they reported having a better sense of what their PFMs were doing (contracting or relaxing), with the Femiscan™ intravaginal probe in place, especially during the isolated hip muscle contractions. This suggests
that participants were better able to feel when co-activation of the PFMs was occurring during isolated hip muscle contractions and may have been better able to relax their PFMs in response to cues from the investigator. If this is the case, then the Femiscan™'s geometry may have aided in reducing co-activation of the PFMs during the isolated hip contraction tasks, and artificially decreased EMG amplitude recorded during the task compared to what would have been recorded without proprioceptive feedback being provided (i.e. with the novel electrode in situ). This potential discrepancy may have fueled an erroneous conclusion that the novel electrode recorded more crosstalk from the hip musculature than the Femiscan™. The results of the study did not support this, however, since the novel electrode appeared to record less crosstalk than the Femiscan™ electrode and therefore, if anything, the geometry of the Femiscan™ probe helped to mask the advantages of the novel electrode in terms of crosstalk contamination.

5.7.4 Influence of Electrode Size on Crosstalk Results

It is also important to acknowledge the impact of electrode size on the crosstalk findings. Because the novel electrode’s detection surfaces were 1/10th of the size of the Femiscan™’s detection surfaces, we expected to record much larger RMS amplitudes from the Femiscan™ compared to the novel electrode. This was not the case during the reliability analysis (See Figure 4.8) but was apparent during the crosstalk analysis where the PFM MVCs recorded with the hip muscles at rest presented (Figures 4-18 and 4-20) demonstrated a tendency for the Femiscan™ electrode to record higher EMG activation amplitudes. Because of this difference, EMG activation amplitudes were not compared between electrodes at each contraction intensity as an indication of crosstalk or co-activation. Comparing the trends within each electrode was deemed to be a more accurate representation of the tendency to record crosstalk or co-activation.
5.8 Crosstalk from the Transversus Abdominis

Neither the novel electrode nor the Femiscan™ appeared to record crosstalk from the transversus abdominis muscle at any intensity of contraction, as average time delays between bursts of transversus abdominis and PFM activity were all greater than or equal to $\Delta = 0.5$ ms, and the peak cross-correlation coefficients were all less than $r = 0.90$. Although previous studies have used similar methods to identify the presence of crosstalk in EMG recordings (Marshall & Murphy, 2003), this method of evaluating the presence of crosstalk using the above parameters has not been validated. A future study should evaluate the validity of using this approach.

5.9 Acceptability of Vaginal Electrode Utilization

The acceptability of insertion of each vaginal electrode was similar, and upon position changes, it was more acceptable to move with the novel electrode in situ than the Femiscan™. These results in particular cannot be generalized to other populations, such as women with sexual pain disorders. Because sexual pain disorders are characterized by pain during any type of vaginal penetration, a disparity in the acceptability of insertion of each vaginal electrode is more likely to be present, due to the large diameter of the Femiscan™ in comparison to the diameter of one digit that is required to position the novel electrode.

5.10 Future Directions

Because the novel electrode was unsuccessful in reducing the incidence of motion artifact present during coughing, a modification of the design to incorporate recessed electrodes may be advantageous. This is currently being pursued in our laboratory.

Because hip muscle contractions in this study were restricted to levels of 25%, 50% and 100% MVC, and crosstalk was generally present by 25% MVC in the Femiscan™ probe, a future
study should investigate the effect of hip muscle contractions at intensities of less than 25 percent of maximal effort in order to determine at what point crosstalk becomes a problem.

The novel electrode appears to be a promising tool for the evaluation of PFM function using EMG. This electrode should be tested on older women, women with urinary incontinence and women with sexual pain disorders in order to determine the feasibility of using it for research as well as in clinical practice.

5.11 Conclusions and Recommendations

Based on the poor to fair between-day reliability of EMG amplitude recorded using the novel electrode, results between days using this electrode should not be compared. However, the novel electrode demonstrates acceptable reliability for use within the same session and may be used to study PFM activity when different tasks or test positions are studied. Furthermore, the novel electrode may be advantageous when performing tasks involving hip muscle contractions in order to provide more valid results than the Femiscan™ probe. Since the design of the Femiscan probe is superior to other commercially available probes, it can be assumed that the novel electrode will outperform most commercially available probes in terms of crosstalk performance.

PFM EMG data recorded using the Femiscan™ probe is more reliable than that recorded using the novel electrode, particularly in terms of between-day reliability, however due to issues related to crosstalk, this probe should only be used when PFM contractions are performed while the hip musculature remains relaxed or contracts at very low levels. Both of the vaginal electrodes recorded a high proportion of data files during coughing that resulted in motion artifact contamination. Vaginal electrode designs that reduce motion artifact in the PFM EMG data are needed.
References


109


Stålberg, E. (2003). Methods for the quantification of conventional needle EMG. In E. Stålberg’s (Ed.), Clinical neurophysiology of disorders of muscle and neuromuscular junction, including fatigue (pp. 213-44). Amsterdam, North Holland: Elsevier B.V.


Appendix

7.1 Commercially Available Intravaginal Probes

7.1.1 Femican™ (Mega Electronics Ltd., Kuopio, Finland)

Source: The Femiscan was identified through a literature review of published papers. It is also commonly used in our laboratory for quantifying muscle activity, as well as for biofeedback.

Description: This commonly used, commercially available electrode probe consists of an L-shaped probe with six longitudinal, stainless steel electrodes evenly spaced around the probe. A single-patient use probe cover (white portion of probe) fits over top of the electrical insert (grey portion of probe). Thus, one can purchase probe covers to place over the re-useable insert. This probe can be used for biofeedback or electrical stimulation (D. Hanneson, oral communication, Biomation Ltd, March 2010).

Dimensions: The width of the probe itself is 2.5cm. Each electrode is 5.8cm in length and 0.3cm wide with an interelectrode distance of 1.0 cm and a total surface area of 1.75cm².

Electrode Configuration: When used in its original configuration, the Femiscan produces one EMG signal (D. Hanneson, oral communication, Biomation Ltd, March 2010). That signal is supposed to be representative of both sides of the PFM s.
7.1.2 T6050 Vaginal Probe (Thought Technology Ltd, Montreal, Canada)

Source: The manufacturer of this probe, Thought Technology, was identified through a literature review of published researched papers. The T6050 vaginal probe was found using the World Wide Web.

Description: The T6050 Vaginal Probe is a T-shaped probe, similar to the Femiscan™, only it features a flared proximal end. There is one detection surface on each side of the probe. According to the manufacturer (Thought Technology Ltd. Sales representative, oral communication, 2010), this probe is used for recording EMG only, not for electrical stimulation.

Dimensions: The T6050 probe is 6.5cm in length, and features a diameter of approximately 1.2cm along its shaft. The diameter at the proximal flared end is approximately 2.6cm. Each electrode is 2.5 cm long and 0.35cm wide (Thought Technology Ltd. Sales representative, oral communication, 2010).

Electrode Configuration: The manufacturer was contacted by phone, and said that only one EMG signal is displayed on the screen when using this probe for biofeedback (Thought Technology Ltd. Sales representative, oral communication, 2010). Thus, one is not able to see the activity from the right and left PFMs separately, as they are treated as the same muscle.

7.1.3 Periform (NEEN Mobilis Healthcare Group, Lancashire, UK)

Source: This probe was found through a literature review of published papers. It has also been previously used in our laboratory for research purposes.
**Description:** The Periform consists of a hollow, pear-shaped probe with one detection surface on each side of the probe.

**Dimensions:** The width of the probe itself, at its widest part, is 3.4 cm. Each recording surface is 3.5 cm long and 1.5 cm wide for a total surface area of 5.25 cm² per detection surface.

**Electrode Configuration:** In its original configuration, this probe will display one EMG signal representing both sides of the PFMs (D. Hanneson, oral communication, Biomation Ltd, March 2010).

### 7.1.4 Veriprobe™ (Verity Medical Ltd, Hampshire, UK)

![Veriprobe™](image)

**Source:** The Veriprobe™ was identified through a literature review of published papers, as well as through the World Wide Web.

**Description:** This probe electrode is tapered at the level of the introitus and features two recording plates on its surface, one on each side of the probe. It can be used for biofeedback, as well as electrical stimulation (Verity Medical Ltd. Sales representative, oral communication, 2010).

**Dimensions:** The probe has a total length of 8.8 cm and a circumference of 8.2 cm. Its width, at the level of the PFMs, is 2.6 cm. Each recording plate is 2.0 cm wide and 3.5 cm long. The interelectrode distance is 2.0 cm.

**Electrode Configuration:** The manufacturer was contacted by phone, and said that the Veriprobe™ does not record from the right and left sides of the pelvic floor separately (Verity Medical Ltd. Sales representative, oral communication, 2010). Instead, one EMG signal is displayed (Verity Medical Ltd. Sales representative, oral communication, 2010), which is supposed to be representative of the muscle activity on both sides of the PFMs.
7.1.5 Pathway™ 6330 Vaginal EMG/Stimulation Sensor (The Prometheus Group, Dover, US)

Source: The Pathway™ 6330 was found using the World Wide Web.
Description: The Pathway™ 6330 features a flared proximal end that rests inside the vagina, as well as protrusion at its distal end that rests outside the vagina. Two electrodes are found on its surface. This sensor can be used for biofeedback or electrical stimulation.
Dimensions: The probe itself is 7.24cm long and 2.75cm in diameter, along its shaft (The Prometheus Group. Sales representative, oral communication, 2010). Each of the two electrodes is 4.19cm long and 1.40cm wide (The Prometheus Group. Sales representative, oral communication, 2010).
Electrode Configuration: The manufacturer responded over the phone one EMG signal is displayed (The Prometheus Group. Sales representative, oral communication, 2010) grouping activity from the right and left PFMs together.

7.1.6 Pathway™ 6630 Vaginal/Rectal EMG Sensor (The Prometheus Group, Dover, US)

Source: The Pathway™ 6630 was found using the World Wide Web.
**Description:** This probe features a consistent diameter across the length to be inserted into the vagina, as well as a distal protrusion that rests outside of the vagina to help keep it in place. It is similar in shape to the Femiscan. Two stainless steel electrodes are positioned on either side of the probe, as well as one electrode that acts as a reference (The Promethius Group. Sales representative, oral communication, 2010). This probe is used for biofeedback only, not electrical stimulation (The Promethius Group. Sales representative, oral communication, 2010).

**Dimensions:** The probe itself is 7.75 cm in length, and 1.82 cm in width (The Promethius Group. Sales representative, oral communication, 2010). Each of the two electrodes is approximately 2.5 cm in length (The Promethius Group. Sales representative, oral communication, 2010), and approximately 1 cm in width.

**Electrode Configuration:** The manufacturer responded over the phone that each electrode is compared to the reference electrode, and the result is one EMG signal (The Promethius Group. Sales representative, oral communication, 2010). Thus, the configuration of the electrodes does not allow the activity from the right and left side of the PFMs to be represented separately.

### 7.1.7 SenseRx™ (SRS Medical Systems, Inc, Redmond, US)

**Source:** This probe was found using the World Wide Web.

**Description:** The SenseRx™ is shaped like a miniature dumbbell, with flaring at both its ends. The top end is positioned inside of the vagina, above the level of the PFMs, whereas the bottom flared end rests outside of the vagina.

**Dimensions:** The SenseRx™ probe is approximately 5 cm in width at its flared end, and 8 cm long (D. Hanneson, oral communication, Biomation Ltd, March 2010). Three stainless steel electrodes are positioned around the probe, 120 degrees apart. Each electrode is 3 cm in length and 0.5 cm in width (D. Hanneson, oral communication, Biomation Ltd, March 2010). Two of those electrodes record PFM activity, whereas the third electrode acts as a reference (D. Hanneson, oral communication, Biomation Ltd, March 2010). This probe can be used for biofeedback or electrical stimulation (D. Hanneson, oral communication, Biomation Ltd, March 2010). The probe is usually positioned such that the active electrodes are positioned at 2 o’clock, and 8 o’clock, and the reference is facing the posterior vaginal wall at 6 o’clock (D. Hanneson, oral communication, Biomation Ltd, March 2010).

**Electrode Configuration:** A local distributor of this production, Biomation Ltd, was contacted by phone and responded that only one EMG signal is seen (D. Hanneson, oral communication, Biomation Ltd,
March 2010). The manufacturer failed to respond to inquiries regarding this probe, although multiple attempts to contact them through both email and phone were made.

7.1.8 EMPI Vaginal Electrode 199271-001 or 199272-001 (EMPI (a DJO company), St. Paul, US)

*Source:* This probe was found by conducting a literature review of published papers.

*Description:* This vaginal probe features an inconsistent diameter across its length, and a slightly flared distal end that rests outside of the vagina. The three circumferential electrodes on this probe are not exposed, but covered by Satoprene (medical grade rubber) (G. Conger, T. Jaros (EMPI Inc), written communication, July 2010). It can be used for both biofeedback and electrical stimulation (EMPI, 2010). The top and bottom electrodes are typically used for electrical stimulation, whereas the middle electrode is used for biofeedback (G. Conger, T. Jaros (EMPI Inc), written communication, July 2010). This probe is unique in that the vaginal probe comes in two different sizes (regular (R) and small (S)) (G. Conger, T. Jaros (EMPI Inc), written communication, July 2010).

*Dimensions:* The probe itself is 6.67 cm (S) 5.72 cm (R) in length (EMPI, 2010). Its proximal end is 8.26 cm (R) or 6.35 cm (S) in circumference (G. Conger, T. Jaros (EMPI Inc), written communication, July 2010). Its distal end is either 8.26cm (R) or 6.67cm (S) in circumference (EMPI, 2010). Regarding the size of each electrode, the proximal circumferential electrode is 1.27 cm wide (R) and (S) (EMPI, 2010). The middle electrode is 1.27 cm wide (R) or 1.02 cm wide (S), and the distal tip electrode is approximately 1.32 cm wide (R) and (S) (G. Conger, T. Jaros (EMPI Inc), written communication, July 2010).

*Electrode Configuration:* When contacted by email, the manufacturer responded that only one EMG signal is seen when performing biofeedback (G. Conger, T. Jaros (EMPI Inc), written communication, July 2010).

7.1.9 Vaginal Sensor VS 2000™ (*Standard Instruments GmbH, Karlsruhe, Germany*)

*Source:* This probe was found using the World Wide Web.

*Description:* The VS 2000™ is shaped like the SenseRx™, with a proximal flaring, and distal protrusion that rests outside of the vagina. Three gold electrodes are positioned on the probe’s surface, two of which are longitudinal, and the one circular electrode acts as a reference (A. Schönfeld, Standard Instruments,
oral communication, July 2010). This probe can be used for electrical stimulation or biofeedback (A. Schönfeld, Standard Instruments, oral communication, July 2010).

**Dimensions:** The manufacturer was contacted through phone, and said they would email the dimensions of the probe and the electrodes, but never followed through. The manufacturer was emailed to remind them about obtaining this information, but never answered.

**Electrode Configuration:** The manufacturer was contacted by phone, and said that one EMG signal is displayed, representing both sides of the PFMs (A. Schönfeld, Standard Instruments, oral communication, July 2010).

### 7.1.10 Femelex (Thought Technology Ltd, Montreal, Canada)

![Femelex Image]

**Source:** This probe was found using the World Wide Web.

**Description:** The Femelex is cone-shaped, and features two large detection surfaces on either side of the probe. It can be used for both biofeedback and electrical stimulation (Thought Technology Ltd. Sales representative, oral communication, 2010).

**Dimensions:** At its proximal end, the Femelex probe is approximately 2.9cm in diameter, and at its distal end, approximately 1.3cm in diameter seen (D. Hanneson, oral communication, Biomation Ltd, March 2010). The length of the probe is approximately 7.5cm. Each electrode is approximately 2.5cm in length seen (D. Hanneson, oral communication, Biomation Ltd, March 2010)

**Electrode Configuration:** The manufacturer was contacted by phone, and said that only one EMG signal is displayed that represents both the right and left sides of the PFMs (Thought Technology Ltd. Sales representative, oral communication, 2010).

### 7.1.11 KS-3 Vaginal Electrode (INNOCEPT Biobedded Medizintechnik GmbH, Gladbeck, Germany)
Source: This probe was found using the World Wide Web.

Description: The KS-3 Vaginal probe has a consistent diameter along its length, and features three circumferential electrodes along its length. This probe can be used for electrical stimulation, or biofeedback (S. Kresse, Innocept Biobedded Medizintechnik GmbH, written communication, August 2010).

Dimensions: The probe itself is 1.2cm wide and 7.1cm long. Each electrode is 0.7cm wide. The dimensions of the probe were available in an online brochure featured on the manufacturer’s website.

Electrode Configuration: The manufacturer was contacted by email, and responded that using the manufacturer’s EMG equipment, only the electrode situated on the left side of the PFMs is used for biofeedback (S. Kresse, Innocept Biobedded Medizintechnik GmbH, written communication, August 2010).

7.1.12 EMG 2-Ring Vaginal Probe (V.M.P Bioparc, Auriol, France)

Source: This probe was identified through a literature review of published research papers.

Description: The 2-Ring Vaginal Probe features a consistent diameter along the shaft that tapers at the level of the introitus. It features two circumferential electrodes on its surface.

Dimensions: The probe itself is 12.7cm long, and has a circumference of 7.7cm at the level of the electrodes. Each electrode is 0.1cm wide.

Electrode Configuration: Unknown, contact information for the manufacturer could not be found. This company may no longer exist.
7.1.13 VT-3 Vaginal Electrode (INNOCEPT Biobedded Medizintechnik GmbH, Gladbeck, Germany)

Source: This probe was found using the World Wide Web.

Description: The VT-3 Features a curved surface that narrows slightly at the level of the introitus. It features two circumferential electrodes on its surface. This probe can be used for electrical stimulation, or biofeedback (S. Kresse, Innocept Biobedded Medizintechnik GmbH, written communication, August 2010).

Dimensions: The probe itself is 2.4cm wide at its largest width, and 9.3cm long. Each electrode is approximately 0.3cm wide. The dimensions of the probe were available in an online brochure featured on the manufacturer’s website.

Electrode Configuration: The manufacturer was contacted by email, and responded that impulses from the each of the two electrodes is represented together (S. Kresse, Innocept Biobedded Medizintechnik GmbH, written communication, August 2010).

Evidence: None available, the reliability of EMG results obtained using the VT-3 Vaginal Electrode has not yet been investigated.
7.1.14 VS 2000 Standard Vaginal Sensor (Haynl Elektronik GmbH, Schönebeck, Germany)

Source: The manufacturing company was found through a literature review of published researched papers. Contact information for the company was found using the World Wide Web, and this probe was identified through a request of information from the manufacturer. It should be noted that the manufacturer is also able to construct custom probes (C. Hentzsch, Haynl Elektronik, written communication, August 2010).

Description: The VS 2000 Haynl Vaginal Sensor is similar in shape to the SenseRx or VS 2000 Standard Instruments Probe. It features two longitudinal electrodes that lie on opposite sides of the probe, as well as a circumferential reference electrode (C. Hentzsch, Haynl Elektronik, written communication, August 2010). It can be used for electrical stimulation, or biofeedback. It should be noted that this company only sells its products in Europe. They do not have Medical Device Licenses for Canada (C. Hentzsch, Haynl Elektronik, written communication, August 2010).

Dimensions: The probe itself is 8.2cm long, and 1.2cm wide along its shaft, at the level of the PFMs (C. Hentzsch, Haynl Elektronik, written communication, August 2010). The proximal flared end is 2.8cm wide, whereas the distal end is 3.8cm wide (C. Hentzsch, Haynl Elektronik, written communication, August 2010). Each of the two longitudinal electrodes is 2.2cm in length, and 0.8cm in width (C. Hentzsch, Haynl Elektronik, written communication, August 2010).

Electrode Configuration: The manufacturer was contacted by email, and responded that only one EMG signal is seen when using this probe for biofeedback (C. Hentzsch, Haynl Elektronik, written communication, August 2010). Thus, the right and left sides of the PFMs are not represented separately.
7.1.15 InCare Vaginal Probe 9597 (Hollister Ltd, Libertyville, US)

Source: This probe was found by contacting a local distributor of pelvic floor equipment (Biomation Ltd).

Description: The InCare Vaginal Probe is similar in shape to the Femiscan or Pathway 6330. It features two circumferential electrodes at its distal end. It can be used for electrical stimulation or biofeedback. This probe is available in three different sizes (D. Hanneson, Biomation Ltd, oral communication, August 2010).

Dimensions: The probe itself is 12.4 cm long and 1.6 cm wide. Each of the two circumferential electrodes is approximately 0.9 cm wide and 6.2 cm long, spanning the circumference of the probe.

Electrode Configuration: The manufacturer did not respond to written communication. Only one connecting cable is present on the probe, thus, only one EMG signal can be seen.
7.1.16 DMI Intravaginal Electrode *(DMI Medical Ltd, Wigan, UK)*

**Source:** This probe was found by contacting a local distributor of pelvic floor equipment (Biomation Ltd).

**Description:** This probe is similar in shape to the InCare Vaginal Probe, although it is shorter and larger in diameter. It features two circumferential electrodes. According to the manufacturer, it can be used for stimulation or biofeedback.

**Dimensions:** The probe itself is 6.8cm long and approximately 2.4cm wide. Each circumferential electrode is approximately 0.9cm wide and 8cm long, covering the circumference of the probe.

**Electrode Configuration:** Only one connecting cable is present on the probe, thus, only one EMG signal is seen.

---

125
7.2 Ethics Approval

QUEEN'S UNIVERSITY HEALTH SCIENCES & AFFILIATED TEACHING HOSPITALS RESEARCH ETHICS BOARD

April 14, 2010

This Ethics Application was subject to:

☐ Full Board Review
☐ Meeting Date:
☒ Expedited Review

Ms. Nadia Keshwani
School of Rehabilitation Therapy
Louise D. Acton Building
Queen’s University

Dear Ms. Keshwani,

Study Title: Electromyography of the Pelvic Floor Musculature: Reliability and Validity of a Novel Electrode Design

Co-Investigators: Dr. Linda McLean

I am writing to acknowledge receipt of your recent ethics submission. We have examined the protocol and consent form for your project (as stated above) and consider it to be ethically acceptable. This approval is valid for one year from the date of the Chair’s signature below. This approval will be reported to the Research Ethics Board. Please attend carefully to the following list of ethics requirements you must fulfill over the course of your study:

➢ Reporting of Amendments: If there are any changes to your study (e.g., consent, protocol, study procedures, etc.), you must submit an amendment to the Research Ethics Board for approval (see http://www.queensu.ca/vpr/reb.htm).

➢ Reporting of Serious Adverse Events: Any unexpected serious adverse event occurring locally must be reported within 2 working days or earlier if required by the study sponsor. All other serious adverse events must be reported within 15 days after becoming aware of the information.

➢ Reporting of Complaints: Any complaints made by participants or persons acting on behalf of participants must be reported to the Research Ethics Board within 7 days of becoming aware of the complaint. Note: All documents supplied to participants must have the contact information for the Research Ethics Board.

➢ Annual Renewal: Prior to the expiration of your approval (which is one year from the date of the Chair’s signature below), you will be reminded to submit your renewal form along with any new changes or amendments you wish to make to your study. If there have been no major changes to your protocol, your approval may be renewed for another year.

Yours sincerely,

[Signature]
Chair, Research Ethics Board

April 14, 2010

Study Code: REH-470-10

➢ Investigators please note that if your trial is registered by the sponsor, you must take responsibility to ensure that the registration information is accurate and complete.
June 15, 2010

Ms. Nadia Keshwani  
School of Rehabilitation Therapy  
Louise D. Acton Building  
Queen's University

Re:  "Electromyography of the Pelvic Floor Musculature: Reliability and Validity of a Novel Electrode Design" REH-470-10

Dear Ms. Keshwani,

I am writing to acknowledge receipt of the following:

- Your email dated Monday, May 31, 2010 requesting approval to position the vaginal electrodes
- Your follow-up email dated Wednesday, June 09, 2010 which included the following:
  - A copy of a medical directive from Dr. Marie-Andrée Harvey
  - A copy of the revised information/consent form

I have reviewed these documents and hereby give my approval. Receipt of these materials will be reported to the Health Sciences Research Ethics Board.

Yours sincerely,

Albert Clark, Ph.D.  
Chair  
Research Ethics Board

AFC/kr

c.c.:  Dr. Linda McLean, School of Rehabilitation Therapy

think Research  
think Queen's
June 24, 2010

Ms. Nadia Keshwani
School of Rehabilitation Therapy
Louise D. Acton Building
Queen’s University

Re: “Electromyography of the Pelvic Floor Musculature: Reliability and Validity of a Novel Electrode Design” REH-470-10

Dear Ms. Keshwani,

I am writing to acknowledge receipt of your request for an amendment to the above-named study. I have reviewed this amendment:

- Request to offer participants $40 for their 4 hours of participation

and hereby give my approval. Receipt of this amendment will be reported to the Health Sciences Research Ethics Board.

Yours sincerely,

[Signature]

Albert Clark, Ph.D.
Chair
Research Ethics Board

AFC/kr

c.c.: Dr. Linda McLean, School of Rehabilitation Therapy

think Research
think Queen's
Do you want to know about your **Pelvic Floor** Muscles?

We are looking for women to participate in a study aimed at testing a new way to evaluate the pelvic floor muscles using electromyography.

**What is Electromyography?**

When your muscles are contracted, they give off an electrical signal. Electromyography picks up this electrical signal...so it can tell when your muscles are contracted and relaxed!

**Study Procedures:**

Use of electromyography, 1 training session & 2 evaluation sessions needed

All information is strictly confidential.

**Interested?**

For more information, please contact the Pelvic Floor Lab

(613).533.6000 Ext 79009

pelvicfloor@queensu.ca

**Investigator:**

Nadia Keshwani, BSc PT, MSc Candidate, Faculty Supervisor: Linda McLean, PhD
**Title of Project:** “Electromyography of the Pelvic Floor Musculature: Reliability and Validity of a Novel Surface Electrode Design”

**Background Information:** You are being invited to participate in a research study directed by Nadia Keshwani (BSc PT, MSc Candidate) under the supervision of Dr. Linda McLean to evaluate the reliability and validity of a new design of surface electrode developed for electromyography assessment of the pelvic floor muscles. Nadia Keshwani will read through this consent form with you and describe the procedures in detail and answer any questions you may have. This study has been reviewed for ethical compliance by the Queen’s University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board.

**Details of the Study:** The purpose of this study is to investigate the reliability and validity of a new design of surface electrode developed for electromyography assessment of the pelvic floor muscles. Electromyography is a tool used to detect muscle activity. When your muscles are contracting they generate an electrical signal. This signal allows us to tell when and how much your muscles are contracted or relaxed. You will be considered for this study if you are a woman between the age of 18 and 50 years old, are not currently pregnant, have not given birth, have no history of incontinence (difficulty controlling bowel and bladder function), pelvic organ prolapse, gynaecological surgeries (Ex. Hysterectomy), do not have any neurological conditions known to influence muscle activity, do not have chronic low back pain, and have not have any serious injuries to your legs in the past 6 months.
What will be required of me? The study will require one training session and two data collection sessions, within the span of two and a half weeks.

During the training session, you will be taught how to perform pelvic floor muscle contractions and hip muscle contractions, and will be familiarized with the test positions required during the evaluation sessions. In order to teach you how to perform a pelvic floor muscle contraction, the research student will insert a lubricated, gloved digit about 2.5 cm into your vagina in order to be able to feel your pelvic floor muscles contracting. This training session will take approximately 40 minutes. You will be asked to return a few days later for the first data collection session. During the first data collection session, you will be asked to: 1) Contract your pelvic floor muscles only, 2) Resist against various hip movements (i.e. pushing your leg inwards against a resistance, & pushing your ankles inwards against resistance to target specific hip muscles, 3) Contract your pelvic floor muscles and hip muscles at the same time, 4) Catch a 1 kg weight when dropped from a specific height, 5) Cough as hard as you can, and 6) Bend your elbows against resistance.

Prior to performing the above tasks, an electrode will be inserted shallowly into your vagina. To do this, the research student will insert a lubricated, gloved digit about 2.5cm into your vagina to find your pelvic floor muscle. Once the specific muscle has been located, the research student will then insert a very small, single patient use, sterilized electrode (1 cm in width) into the vagina, and firmly but gently press it onto the side of the vaginal wall. A gentle but firm suction force will then stick the electrodes on to your vaginal wall. This method will be repeated on the other side of your vaginal wall. The insertion of the electrodes will take approximately 5 minutes. Another electrode will then placed onto the skin over your biceps muscles, using an easy to remove adhesive tape.

Once the electrodes are in place, you will be asked to perform the above tasks. This portion of the evaluation will take approximately 45 minutes. The electrodes will be removed and you will then be given a device that has electrodes embedded on its sides to insert into your vagina on your own. The research student will verify that you have inserted the device properly before beginning data collection. You will repeat the same series of contractions of your pelvic floor, abdominal and hip muscles, as well as coughing. Again, this portion should take 45 minutes. You will remove the device from your vagina, and this will complete the first data collection session. You will be asked to return to the laboratory approximately one week later to repeat a small part of the data collection protocol.

On the second evaluation the same electrodes used during the first evaluation session will be inserted and adhered to your vaginal wall as was done previously. Because we are interested in examining the reliability (i.e. of consistency) of results across days during isolated pelvic floor and biceps contractions, only these tasks need to be repeated during the second evaluation session.

Thus, once the electrodes are in place, you will be asked to perform three repetitions of three standardized tasks: 1) Contracting your pelvic floor muscles, 2) Catching a 1 kg weight when dropped from a height of 30 centimetres, 3) Contracting your biceps muscles. Once you have
completed these tasks, all of the electrodes will be removed. The second evaluation session
should take no more than 45 minutes.

Are there any risks to doing this study? You might experience muscle soreness 24-48 hours
after participating in the study if you are not used to contracting the muscles as you will be doing
in this study. This muscle soreness, if it occurs, is a normal response and is not known to be
harmful to your muscles. There is a small chance that you will experience a small amount of
bleeding from that vaginal wall associated with the electrode due to abrasion or pressure from
the electrodes. We will minimize this risk as much as possible by applying only a small (<1cc)
amount of suction pressure to hold the electrodes in place. You will be the one controlling how
much suction pressure is applied to ensure that you are comfortable with the amount of suction
applied. If you experience any side effects during the study, please let the researchers know
immediately. If you experience any side effects after participating in the study, please contact
the researchers at the number provided at your earliest convenience (Nadia Keshwani, (613) 888
9289).

Are there any benefits to doing this study? There are no direct benefits for participating in this
study. Through participating in this study, you will gain knowledge about your pelvic floor
muscles, and you will be taught how to properly contract them. Properly contracting your pelvic
floor muscles has been shown to be an effective preventive and treatment approach for
incontinence and pelvic organ prolapse in women. Also, by being a participant in this study, you
will be contributing to formation of better assessment tools for the pelvic floor muscles in
women.

What will happen to my information? All the information we collect during your visits will be
kept confidential. To make sure that confidentiality is maintained, your name will not appear on
any of the actual data. Instead, all of the information collected will identify you only by a
participant ID number rather than your name, and the electronic file which matches up
participant names and ID numbers will be password-protected. Only experimenters within the
pelvic floor laboratory at Queen’s University will have access to this information. The data may
be published in professional journals or presented at scientific conferences, but any such
presentations will be of general findings and will never reveal your identity. Should you be
interested, you are entitled to a copy of the findings.

Is my participation voluntary? Yes. You may withdraw from this study at any time and
without any effect on your standing in school, if you are a student.

What happens if I’m injured? In the event that you are injured as a result of the study
procedures, medical care will be provided to you until resolution of the medical problems occurs.
By signing the below consent form, you do not waive your legal rights nor release the
investigators from their legal and professional responsibilities.

Will I be compensated for my participation? You will receive $40 upon completion of the
study.

What if I have concerns? In the event that you have any complaints, concerns, or questions
about this research, please feel free to contact Nadia Keshwani; 8nk23@queensu.ca; project
supervisor, Dr. Linda McLean (533-6101); mcleanl@queensu.ca; or Albert Clark, the Chair of the Health Sciences Research Ethics Board (533-6081) at Queen’s University.

Again, thank you! Your interest in participating in this research study is greatly appreciated.
Consent Form

I have read and understand the consent form for this study. I have had the purposes, procedures, and technical language of this study explained to me. I have been given sufficient time to consider the above information and to seek advice if I choose to do so. I have had the opportunity to ask questions which have been answered to my satisfaction. I am voluntarily signing this form. I will receive a copy of this consent form for my information.

If at any time I have further questions, problems, or adverse events, I can contact

Nadia Keshwani at 613 888-9289

or

Elsie Culham at 613 533-6727
Director of the School of Rehabilitation Therapy

If I have any questions regarding my rights as a research subject I can contact
Dr. Albert Clark, Chair, Queen’s University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board (533-6081)

By signing this consent form, I am indicating that I agree to participate in this study.

Signature: __________________________ Date: ___________________
Electromyography of the Pelvic Floor Musculature: Reliability and Validity of a Novel Surface Electrode Design

Hip Adduction in Sidelying

**Position:** Lie on your right side, with your left leg bent, and left foot on the floor.

**Action:** Keeping your pelvic floor muscles relaxed, lift your right leg ~6 inches off the floor. Hold for 5 seconds. Slowly lower your right leg to the floor. Repeat 5 times, for the next 2 days.

*Variation:* Contract your pelvic floor muscles as hard as you can, then lift your right leg ~6 inches off the floor. Hold your right leg off the floor for 5 seconds, keeping your pelvic floor muscles contracted. Slowly lower your leg to the ground. Repeat 5 times, for the next 2 days.

Hip External rotation in Prone

**Position:** Lie on your stomach, with your left leg laying flat on the ground, and your right thigh on the floor. Keeping your right thigh on the floor, bend your right knee so that your lower leg is perpendicular to the floor.

**Action:** Keeping your pelvic floor muscles relaxed, and keeping your right thigh on the floor, rotate your right leg so that your right ankle moves closer to your left knee. (Your right ankle will not reach your left leg. Bring your right ankle as far towards your left leg as is comfortable. This should not be painful. Return to starting position. Repeat 5 times, for the next 2 days.

*Variation:* Contract your pelvic floor muscles as hard as you can, then perform the above motion. Repeat 5 times, for the next 2 days.
Title of Project: “Electromyography of the Pelvic Floor Musculature: Reliability and Validity of a Novel Surface Electrode Design”

Background Information: You are being invited to participate in a research study directed by Nadia Keshwani (BSc PT, MSc Candidate) under the supervision of Dr. Linda McLean to evaluate the validity of a new design of surface electrode developed for electromyography assessment of the pelvic floor muscles. Nadia Keshwani will read through this consent form with you and describe the procedures in detail and answer any questions you may have. This study has been reviewed for ethical compliance by the Queen’s University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board.

Details of the Study? The aim of this study is to investigate the validity of a new design of surface electrode developed for electromyography assessment of the pelvic floor muscles. Electromyography is a tool used to detect muscle activity. When your muscles are contracted, they generate an electrical signal, so it allows us to tell when your muscles are contracted, and when they are relaxed. You will be considered for this study if you are a woman between the age of 18 and 50 years old, have not given birth, have no history of incontinence (difficulty controlling bowel and bladder function), pelvic organ prolapse, gynaecological surgeries (Ex. Hysterectomy), do not have chronic low back pain, and have not have any injuries to your legs in the past 6 months. It is also important that you do not have a fear of needles, as a needle will be inserted into your abdominal muscles (see below).

What will be required of me? The study will require one training session and one evaluation session, within the span of one week. During the training session, you will be taught how to perform a proper lower abdominal contraction. You will also be taught how to perform a proper pelvic floor muscle contraction. In order to feel when your pelvic floor muscles are contracting, the examiner will insert one lubricated, gloved digit shallowly into your vagina. This training session will take approximately 15 minutes.

You will be asked to return approximately 1 week later for the evaluation session. During this session, you will be asked to: 1) Contract and then relax your pelvic floor muscles 10 times, 2) Contract and then relax your lower abdominal muscles 10 times, each task being repeated three times.

Before the evaluation begins, an electrode will be inserted shallowly into your vagina. To do this, the research student, Nadia Keswani, will insert a lubricated, gloved digit about 2.5cm into your vagina to find your pelvic floor muscle. Once the specific muscle has been located, the research
student will then insert a very small disinfected electrode (1 cm in width) into the vagina, and firmly but gently press it onto the side of the vaginal wall. A gentle but firm suction force will then stick the electrodes on to your vaginal wall. This method will be repeated on the other side of your vaginal wall. The insertion of the electrodes will take approximately 5 minutes.

Fine wire electrodes will also be inserted into your abdominal muscles in order to record muscle activity from these muscles at the same time as recording the activity from your pelvic floor muscles. The fine wire electrodes will be inserted by Dr. Linda McLean, who has experience with this technique. The electrodes are inserted using a single use needle cannula (a slender, hollow tube) that, once the wires are in the appropriate position, is withdrawn. The wires remain in your muscle for data collection. Like receiving an injection or having blood drawn, there is sometimes mild discomfort associated with the insertion of the needle, but this should subside within 10 minutes of removing the needle. You should not feel the wires in your muscle during the tasks.

Once the abdominal and vaginal electrodes are in place, you will then be asked to perform the above tasks. This portion of the evaluation will take approximately 20 minutes.

The vaginal electrodes will then be removed and you will then be given a device that has electrodes embedded on its sides to insert into your vagina on your own. The researcher will verify that you have inserted the device properly before beginning data collection.

With the abdominal electrodes still in place, and this second vaginal electrode inserted, you will be asked to perform the same two tasks as above. Once you have completed these tasks, all of the electrodes will be removed. The wire electrodes are easily removed by a quick tug. This evaluation session should approximately 1 hour.

**Are there any risks to doing this study?** It is possible that you may experience some discomfort due to the insertion of the needle cannula and wire electrodes into your abdominal muscles, but as noted above, this should subside within 10 minutes of insertion. Please inform the researchers immediately if the wire electrodes cause discomfort beyond the period that the needle cannula is inserted in the muscle. If this is the case, the wires will be removed and replaced.

Whenever the skin is pierced, as occurs with the insertion of a needle, there is a risk of infection. In order to minimize this risk, your skin will be cleaned with rubbing alcohol and allowed to dry before each needle is inserted. Each needle is single-use, and sterilized prior to its insertion. You might experience muscle soreness 24-48 hours after participating in the study if you are not used to contracting the muscles as you will be doing in this study. This muscle soreness, if it occurs, is a normal response and is not known to be harmful to your muscles. There is a small chance that you will experience some bleeding from that vaginal wall associated with the electrode due to abrasion or pressure from the electrodes. We will minimize this risk as much as possible by applying only a small (<1cc) amount of suction pressure to hold the electrodes in place. If you experience any side effects during the study, please let the researchers know immediately. If you experience any side effects after participating in the study, please contact...
the researchers at the number provided at your earliest convenience (Nadia Keshwani, 613 888 9289).

**Are there any benefits to doing this study?** There are no direct benefits for participating in this study. Through participating in this study, you will gain knowledge about your pelvic floor muscles, and you will be taught how to properly contract them. Properly contracting your pelvic floor muscles has been shown to be an effective preventive and treatment approach for incontinence and pelvic organ prolapse in women. You will also be taught how to perform a proper lower abdominal contraction. The lower abdominals have been shown to play a role in the prevention and treatment of low back pain. Also, by being a participant in this study, you will be contributing to formation of better assessment tools for the pelvic floor muscles in women.

**Is my participation voluntary?** Yes. You may withdraw from this study at any time and without any effect on your standing in school, if you are a student.

**What will happen to my information?** All the information we collect during your visits will be kept confidential. To make sure that confidentiality is maintained, your name will not appear on any of the actual data. Instead, all of the information collected will identify you only by a participant ID number rather than your name, and the electronic file which matches up participant names and ID numbers will be password-protected. Only experimenters within the pelvic floor laboratory at Queen’s University will have access to this information. The data may be published in professional journals or presented at scientific conferences, but any such presentations will be of general findings and will never reveal your identity. Should you be interested, you are entitled to a copy of the findings.

**What happens if I’m injured?** In the event that you are injured as a result of the study procedures, medical care will be provided to you until resolution of the medical problems occurs. By signing the below consent form, you do not waive your legal rights nor release the investigators from their legal and professional responsibilities.

**Will I be compensated for my participation?** No monetary compensation will be provided.

**What if I have concerns?** In the event that you have any complaints, concerns, or questions about this research, please feel free to contact Nadia Keshwani; 8nk23@queensu.ca; project supervisor, Dr. Linda McLean (533-6101); mcleanl@queensu.ca; or the Chair of the General Research Ethics Board (533-6081) at Queen’s University.

Again, thank you! Your interest in participating in this research study is greatly appreciated.
Consent Form

I have read and understand the consent form for this study. I have had the purposes, procedures, and technical language of this study explained to me. I have been given sufficient time to consider the above information and to seek advice if I choose to do so. I have had the opportunity to ask questions which have been answered to my satisfaction. I am voluntarily signing this form. I will receive a copy of this consent form for my information.

If at any time I have further questions, problems, or adverse events, I can contact

Nadia Keshwani at 613 888-9289

or

Elsie Culham at 613 533-6727
Director of the School of Rehabilitation Therapy

If I have any questions regarding my rights as a research subject I can contact

Dr. Albert Clark, Chair, Queen’s University Health Sciences and Affiliated Teaching Hospitals
Research Ethics Board (533-6081)

By signing this consent form, I am indicating that I agree to participate in this study.

Signature: ____________________________ Date: ______________________
7.8 Abdominal and Pelvic Floor Muscle EMG Data from Subject 1

Figures A, B, and C represent filtered EMG data from Subject 1’s transversus abdominis and PFMs (recorded using the Femiscan™), during 25% MVC, 50% MVC, and 100% MVC contractions of the transversus abdominis.
Figures A, B, and C represent filtered EMG data from Subject 1’s transversus abdominis and PFMs (recorded using the novel electrode), during 25% MVC, 50% MVC, and 100% MVC contractions of the transversus abdominis.
Figures A, B, and C represent filtered EMG data from Subject 2’s transversus abdominis and PFMs (recorded using the Femiscan™), during 25% MVC, 50% MVC, and 100% MVC contractions of the transversus abdominis.
Figures A, B, and C represent filtered EMG data from Subject 2’s transversus abdominis and PFMs (recorded using the novel electrode), during 25% MVC, 50% MVC, and 100% MVC contractions of the transversus abdominis.
Figures A, B, and C represent filtered EMG data from Subject 2’s internal oblique and PFMs (recorded using the Femiscan TM), during 25% MVC, 50% MVC, and 100% MVC contractions of the internal oblique muscle.
Figures A, B, and C represent filtered EMG data from Subject 2’s internal oblique and PFMs (recorded using the novel electrode), during 25% MVC, 50% MVC, and 100% MVC contractions of the internal oblique muscle.