RELIABILITY OF ELECTROMYOGRAPHY DETECTION SYSTEMS FOR
THE PELVIC FLOOR MUSCLES

By

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Abstract

The purpose of this study was to investigate the reliability of three different electromyography (EMG) detection systems commonly used to acquire EMG data from the pelvic floor muscles (PFM) at rest, during maximum voluntary contractions (MVCs) and during a coughing task. Twelve nulliparous women between the ages of 24 and 40 participated in the study. EMG data were recorded from each side of the pelvic floor using surface (Femiscan™ and Periform™ vaginal probes), and fine-wire electrodes while subjects performed three repetitions of each task in supine and in standing. RMS amplitudes of baseline and peak PFM activity were computed from the data acquired during the MVC and the coughing tasks. The peak RMS amplitudes from the cough data were also normalized to each subject’s MVC and report as a percent of their maximum voluntary electrical activation (% MVE). Signal to noise ratio (SNR) was calculated for each task. Comparisons were made between the RMS amplitudes and SNR recorded from each side of the PFM. Between-trial and between-day reliability was determined using a variety of measures including intraclass correlation coefficients (ICC), coefficients of variation (CV) and mean absolute difference (MAD). The reliability of the different devices was compared using the MAD normalized to average signal amplitude (nMAD). The results indicated that the EMG data recorded from the right and left sides of the PFM were different, therefore the EMG data acquired from each side of the pelvic floor were analyzed separately. Between-trial reliability assessed by ICC was good for all the devices (left and right average ICC = 0.80 – 0.96); the CVs supported these findings (average CV = 12.4 – 17.1%). Between-day reliability was poor and inconsistent across all devices and tasks. When the cough data were normalized however, the between-day RMS amplitudes were very consistent (79.5 – 90.2% MVE). Each device recorded consistent activation amplitudes within a given day. Between-day reliability
results indicate that EMG data recorded on separate days with these instruments should not be compared unless data can be normalized. Clinicians and researchers are cautioned to normalize their data if day-to-day comparisons in EMG amplitude are to be made using data recorded with these devices.
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Pelvic floor muscle dysfunction has been identified as one factor that contributes to the common complaint (30-50%) of stress urinary incontinence (SUI) in women. Electromyography (EMG) is widely used to test the neuromuscular function of the pelvic floor muscles (PFM). Fine-wire, needle, and surface electrodes have all been used to describe the activation of the PFM. The PFM are located deep within the bony pelvis making them a challenging group of muscles to develop standardized electrode locations for valid and reliable EMG recordings. Fine-wire electrodes may be more selective at recording from a localized area and have greater precision when detecting muscle onset and offset, however, they are considered to be more invasive than surface electrodes and require special training of technicians or research assistants for insertion. A less invasive technique for recording surface EMG from the PFM has been to use a vaginal probe that has detection electrodes embedded on its surface from which EMG signals are recorded from the vaginal wall surface adjacent to the PFM. There are pitfalls associated with the use of vaginal probes including motion artifact due to probe movement, electrode shorting due to the moist environment within the vagina, and poor electrode contact with the PFM due to the probe geometry and individual anthropometric variability.

1.1 RELIABILITY OF PFM EMG

The reliability of different methods of collecting EMG data from the PFM has not been established. The test-retest reliability of one type of probe that records surface EMG signals from the PFM was tested by Thompson and colleagues\(^3\) on a small sample (n=5) and was found to have excellent reliability (ICC = 0.98, SEM = 0.06). Intra-subject reliability was reported by Deindl and colleagues,\(^4\) to be excellent when PFM EMG was measured on the same day using
fine-wire electrodes (n=20), however no statistical measures were reported to validate this statement. The instruments used to record EMG from the PFM need to be tested for both intra-subject and inter-subject reliability, and ideally, they should be tested during tasks that are commonly used to assess PFM function. It is important to measure the reliability in different test positions to identify changes in the relative position of the detection surface with respect to the muscle fibers of the PFM as changes in electrode locations are known to affect the EMG amplitude and frequency characteristics of the recorded signal. Changing positions can also alter the subjects ability to perform the tasks consistently, e.g. discomfort of probe in certain positions.

1.2 SIDE TO SIDE VARIATION IN PFM EMG ACTIVITY

It is accepted that healthy PFM contract bilaterally as a functional unit. Following vaginal delivery, partial denervation of the PFM and/or unilateral damage may occur such that ineffective motor output to the PFM with voluntary effort or during coughing may result in asymmetrical activation. Overall, the evidence describing the symmetry of activation of the right and left sides of the PFM remains inconclusive. Authors have reported symmetrical activation in healthy women and asymmetrical activation in women with incontinence. Most researchers neglect to discuss the relationship between the different sides of the PFM at all. Despite the PFM having distinct anatomical attachments and neurovascular supply, characteristics obtained from the EMG signals recorded from the two sides of the PFM, such as amplitude, are often reported as a single value. Further, authors do not describe how they calculated the single value from the bilateral EMG signal(s) that were recorded making it difficult to make comparisons between studies. At this point the full extent to which side to side differences contribute to pelvic floor dysfunction is unknown. Until more conclusive evidence is
available to suggest otherwise, it appears to be appropriate to treat the right and left sides of the pelvic floor as separate and distinct muscles.

1.3 CROSSTALK

Crosstalk is described as myoelectric signals that are detected by a local recording electrode over a muscle of interest, but produced by neighbouring muscles. When using surface electrodes to record EMG, crosstalk can be a significant issue that needs to be addressed. Specifically, when recording the EMG activation of the PFM with surface electrodes placed intravaginally, it is accepted that crosstalk can easily contaminate the recorded signal. Crosstalk is a potential problem with many vaginal EMG probes since the recording surfaces on the probes tend to be large in comparison to the size of the PFM. This problem may be worse when using probes with monopolar configurations. A number of investigations address the issue of crosstalk, however, the evidence does not rule out crosstalk as a factor which biases the signal. Low subject numbers, inappropriate evaluations, and a lack of detail in the description of testing are common problems identified when crosstalk is reported.

1.4 PURPOSE

Recent literature suggests that pelvic floor muscle dysfunction may contribute to urinary incontinence, low back pain, and perhaps even respiratory disorders. As researchers continue to evaluate how the PFM function in healthy women and how function is altered in women with known conditions (e.g. stress urinary incontinence), it is essential to take signal reliability and validity into account when interpreting research findings that report EMG parameters from the PFM.

The purpose of this thesis was to determine the reliability of three different instruments commonly used to record the EMG activity during voluntary and reflex activation of the PFM.
Surface EMG data were recorded bilaterally from the PFM using bipolar surface electrodes (using the Femiscan™ vaginal probe), monopolar surface electrodes (using the Periform™ vaginal probe), and bipolar intramuscular fine-wire electrodes inserted into the anterior medial portion of the pubococygeus muscle. First, the EMG signals recorded from the right and left sides of the PFM were compared separately for each detection system. Next, between-trial and between-day (test-retest) reliability was determined for each instrument during PFM maximum voluntary contractions and during coughing in standing and supine. The reliability results were compared in order to determine the utility of each system in research where PFM EMG data acquisition and processing is involved.

1.5 HYPOTHESIS

The right and left sides of the PFM are expected to produce different RMS amplitudes during all tasks when the Femiscan™ vaginal probe and fine-wire electrodes are used to record EMG from the PFM. However, the Periform™ vaginal probe, with its large monopolar detection surfaces, is expected to record similar amplitudes from both the right and left sides of the PFM. Between-trial reliability is expected to be good with all instruments and more consistent than between-day reliability, which is anticipated to be poor. It is also thought that when the EMG data recorded during the cough data are normalized, the between-day reliability will be higher.
The discovery of a relationship between electricity and muscle contraction by Luiggi Galvani in 1791 is thought to be the birth of neurophysiology. Galvani demonstrated that the muscles in frog’s legs could be depolarized using two metal rods, resulting in muscular contraction. Since that time, recording techniques and applications using electromyography (EMG) have continued to evolve. EMG is the study of muscle function through the analysis of the electrical signal generated during muscular contractions. EMG is a useful measurement tool that can be used qualitatively or quantitatively for clinical and research applications. It is well accepted that the amount of force a muscle can produce is to some degree related to the amplitude of the EMG signal. As a clinical diagnostic tool, specialized techniques are used to identify peripheral nerve damage (lesions, entrapments, compression), to study neuromuscular disease processes, and to monitor the progression of neuromuscular conditions over time. In rehabilitation, EMG is frequently used as a form of biofeedback to facilitate muscle re-education by increasing or decreasing activation. In the rehabilitation literature, EMG is used for a variety of research purposes such as quantifying the magnitude of muscle activation, comparing the timing properties of muscle synergies, and to explore relationships between muscle activation and many other biomechanical parameters (e.g. force production).

The EMG signal originates from an electro-chemically mediated event that is initiated in the central nervous system. A motor unit is the functional unit that gives rise to voluntary or reflex contractions in skeletal muscle and includes the alpha motor neuron, its axon, and all the muscle fibers that it innervates. A contraction begins with the excitation of the alpha motor neuron cell body in the anterior horn cell of the spinal cord that then sends an impulse along its
axon and eventually to the neuromuscular junction. When the impulse arrives at the synaptic terminal, a chemical neurotransmitter (acetylcholine (Ach)) is released which then binds to nicotinic receptors on the motor endplate of the muscle membrane. Voltage gated ion channels open which favor the influx of Na+ ions, leading to a depolarization at the muscle membrane that travels throughout the muscle fibers as an action potential. The motor unit potential that results is the spatial and temporal summation of the action potentials from all of the fibers belonging to a given motor unit. The EMG signal is the summation of all of the motor unit potentials within the electrode pick-up area. Therefore, EMG amplitude directly represents the outflow of motoneuron activity.

The myoelectric activity can be detected externally from the skin surface or from within the muscle itself using needle or fine-wire electrodes. Intramuscular electrodes are favourable when recording from muscles that are small or deep within the body, whereas surface electrodes are preferable when the muscles are large and more superficial. The EMG signal contains information in both the frequency and time domains, and representative parameters are computed in both domains in order to characterize muscle activity. The raw signals are often processed using a combination of hardware (electrical circuitry) and software (mathematical equations to amplify, filter or smooth), before the signal parameters such as amplitude or frequency are computed for analysis. Intra- and intersubject differences are expected due to many intrinsic and extrinsic factors (for a more detailed description see DeLuca⁵) and complicate the conclusions that can be drawn from the recorded signal. Following recommendations made by the SENIAM project (Surface Electromyography for the Non-Invasive Assessment of Muscle) can help to optimize the validity and reliability of the EMG signals.²³
2.2 TYPES OF EMG ELECTRODES

An electrode containing some type of detection surface is used to acquire motor unit activity from contracting muscles. Various types of electrodes are available which are constructed out of a variety of materials. The type of electrode used is dependent on the purpose of the investigation, the characteristics of the muscle of interest, and subject comfort. Surface and intramuscular electrodes (needle or fine-wire) are most commonly used. Both surface and intramuscular electrodes may be used in bipolar or monopolar configurations.

2.2.1 SURFACE ELECTRODES

Surface electrodes record the electrical potential of contracting muscles from the skin surface. In 1912, Piper, a German scientist, was one of the first people to use a metal plate as a surface electrode to detect EMG signals from human muscle.\(^2^1\) The signal recorded from surface electrodes is the summation of activity from a large number of motor units which are detected at the skin electrode interface. They are a popular choice in clinical and research settings due to their ease of use. Not only are they easy to apply and readily available, but surface electrodes have the advantage of being a cost effective, non-invasive, and a practical way to record muscle activity over large muscles. When surface electrodes are used following the recommendations made by SENIAM\(^2^3\) they are valuable in identifying if and when a muscle is “on” or “off”, if there is an increase or decrease in activity during a contraction/task, and describing changes in the amplitude and frequency content of a signal during fatiguing contractions.
2.2.1.1 ELECTRODE MATERIAL

The type of surface electrode most commonly used today are self-adhesive and made of silver-silver chloride (Ag/AgCl). They are recessed to minimize the effects of motion artifact on the quality of EMG data recorded. The location of the PFM and moist environment of the vaginal lumen preclude the use of self-adhesive recessed surface electrodes for EMG acquisition of the PFM.

2.2.1.2 ELECTRODE CONFIGURATION

EMG signals can be recorded from the surface of the skin using two or more electrodes. Using a monopolar configuration the electrical potential is detected under the active electrode (cathode), which is placed over the muscle or nerve that is under study. A second electrode (the anode), is often placed over the tendon of the muscle or combined with the reference electrode which is placed on an electrically neutral area of the body (e.g. over a bony prominence). The two signals are relayed through the pre-amplifier where the difference between sites is calculated and compared to the common reference electrode. This configuration is relatively simple, and is often used in electrodiagnostic studies. The monopolar electrode will inherently record all of the electrical activity in its pick-up area which often includes crosstalk and noise. To overcome the problem of recording unwanted signals, surface electrodes can be used in a bipolar configuration combined with a differential amplifier. In this type of set-up, two electrodes are positioned on the skin overlying the muscles at a set distance apart. The signals are recorded independently from the two electrode sites and from a reference electrode placed on tissue that is electrically neutral, the signals are subtracted (from both recording sites and from the reference electrode) prior to amplification, thereby removing any signals that are common to the recording sites. The differential configuration acts as a high pass filter, the higher frequency signals originating from further away from the detection surface will attenuate
over the distance traveled therefore the signal will look similar to both electrodes and thus be subtracted out by the amplifier. The ability of the amplifier to remove unwanted signals is described as the common mode rejection ratio (CMRR) and it is recommended that to obtain a signal of good quality, the CMRR of the EMG amplifiers should be less than 80 dB.\(^5\)

Another source of noise is movement artifact. It is normally controlled for by high input impedance amplifier and through the use of recessed electrodes where motion of the electrode on the skin is minimized. Recessed electrodes are not appropriate for use when recording EMG data from the PFM. Again, the detection surface shape and size as well as the distance between the two electrodes are factors which affect the amplitude and frequency components of the signal. Differential recordings are most common in modern EMG applications.

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2.2.1.3 ELECTRODE DETECTION REGION

Internal properties of the muscle, (physiological, biochemical, and anatomical), have a significant effect on the EMG signal characteristics recorded using surface electrodes, and are not modifiable.\(^5\) The number of motor units which are active as the muscle contracts, the fiber diameter, the depth of the active fibers within the muscle relative to the recording electrode, and the amount and type of tissue between the detection surface and the muscle membrane affect the EMG signal amplitude and frequency characteristics. The biochemical properties and metabolite composition within the muscle at any one time is dependent on fiber type composition and the amount of blood flow to the active muscle which can have a direct affect on the contractile properties of the muscle. Another important consideration is the effect of tissue filtering which directly affects the amplitude and frequency characteristics. The distance between the electrode and the surface of the muscle being recorded from will determine the amount of tissue filtering that occurs. Surface EMG signals detected on an individual with more
subcutaneous adipose tissue will have smaller amplitudes and lower frequency components when compared to the signal recorded from a similar pool of motor neurons without the overlying fatty tissue.

Surface electromyography (SEMG) has been criticized for its inability to selectively record from deep muscles and for its susceptibility to crosstalk. Due to the volume conducting nature of the body tissues, impulses generated from muscles other than the target muscle can be recorded by electrodes placed over the target muscle.

2.2.1.4 ELECTRODE LOCATION

Electrode structure and position relative to the muscle fibers are extrinsic factors that can affect the amplitude and frequency of the EMG signal being recorded. With careful consideration and planning the extent to which these factors influence the EMG signal can be minimized. The location of the electrode with respect to the motor point and myotendinous junction of the muscle will affect the amplitude of the signal, while its position relative to the lateral boarder of the muscle may influence the amount of crosstalk that can be picked up by the recording electrode. The electrode shape and size will determine how many active motor units are within the detection area of the electrode. When using two electrodes in a differential or bipolar configuration, the distance between the two recording surfaces will in part determine the bandwidth of the signal. The conduction velocity of the action potentials that are recorded, the amplitude of the signal, and the power of the signal will all be affected by the orientation of the electrode with respect to the direction of the muscle fibers. The skin temperature and amount of humidity in the air will also influence the signal characteristics to some extent. Moisture between the skin surface and electrodes can lead to electrical shunting which may lead to a decrease in signal amplitude and filtering of higher frequency components of the
When surface electrodes are mounted onto vaginal probes to acquire EMG data from the PFM, the temperature and the moisture within the vaginal lumen is almost impossible to control between days which may influence the amplitude and frequency content of the EMG data recorded.

As described above, the importance of electrode positioning is critical to the reliability and validity of the EMG signal. A variety of studies have been performed in the last 50 years to determine optimal electrode placements for most skeletal muscles. It is recommended to stay away from the innervation zones when placing surface electrodes on muscles. The innervation zone, commonly referred to as the motor point, can be described as the area of the muscle that has the greatest neural density; it is the area where the neuromuscular junction is located and action potentials begin their propagation along the muscle fibers.\(^{24}\) It is important when positioning bipolar surface electrodes that the detection surfaces are not straddling the innervation zone of the muscle. In a bipolar or differential recording it is thought that when the electrode is placed over the innervation zone the signal amplitude may be reduced due to cancellation as a result of signal propagation in both directions. Resources are available that have identified the motor points of most trunk and limb muscles,\(^{25}\) although it is always best to determine the motor point locations on an individual basis as there is large variability in motor point locations between individuals. De Luca\(^ {24}\) recommends placing surface electrodes along the longitudinal midline of the muscle and either between two motor points or between the motor point and the musculotendinous insertion. The estimated number of motor points and their locations in the PFM has not yet been determined. It is accepted that there are differences among individuals in the structure (e.g. cross sectional area) and position of the PFM within the bony pelvis, therefore it is unknown where the fixed detection surfaces on a particular vaginal
probe is positioned relative to the individuals’ PFM once the probes are inserted into the vaginal canal.

SEMG is a useful measurement tool for detecting the activation of many muscles, including the PFM. The PFM do not contain much adipose tissue that could attenuate the signal. Surface electrodes that are embedded on a vaginal probe have a fixed interelectrode distance and the fixed position of the electrodes on the probe helps to keep the electrode spacing consistent between days. However, the fixed electrode distances may not be optimal considering the variability of anthropometric measures across individuals.

2.2.2 FINE WIRE ELECTRODES

Fine-wire electrodes are the most common indwelling electrode used in kinesiological EMG. They have higher spatial resolution than surface electrodes and can be used to detect single motor unit activity. The use of fine-wire electrodes became a popular choice of electrode in the 1960’s due to their small pick-up area and they are relatively painless once inserted. They are suitable when recording from muscles where the use of surface electrodes is not appropriate, in muscles with small cross sectional areas, and when greater precision in estimating the onset and offset of muscle activity is required. The small recording area of wire electrodes helps to minimize signal contamination from electrical potentials generated in neighbouring muscles, e.g. crosstalk.

2.2.2.1 ELECTRODE MATERIALS

A variety of metals and insulating materials have been used in the past to make fine-wire electrodes. It is common for trained individuals to construct their own fine-wire electrodes for research applications. The electrodes are then sterilized and packaged for single-use with subjects. For a more detailed description of materials and construction of these electrodes refer
to *Muscles Alive (p 30-31).* The tips of the wires are stripped of the insulating material to allow signals from nearby muscle fibers to be recorded. The shape of the tips can vary depending on the purpose of the study and the potential for electrode migration during the testing procedures. The tips of the electrodes can be hooked, left straight, or coiled. Coiled tips were found to improve the stationarity of the recorded signal without causing any more damage to the muscle fibers when compared with straight tipped electrodes. The insulated wires are fed through a hypodermic needle exposing the tips that have been stripped of insulation. In most cases, two wires with two separate and offset detection surfaces are inserted into the muscle belly using a small needle, creating a bipolar pair. Once the wires are in the appropriate position, the needle is removed leaving the wires embedded in the muscle fibers.

### 2.2.2.2 ELECTRODE CONFIGURATION

The difference between the two detected signals is amplified to remove signals that are common to both detection surfaces, similar to the differential configuration previously described for surface electrodes. To improve the accuracy and efficiency of electrode placement, real time ultrasound and oscilloscopes have been used. Once the needle is removed from the tissue the wires remain in the muscle, however, subjects normally report no discomfort and are able to move somewhat freely. Basmajian and De Luca state that in their extensive experience with fine wires, that they have not had any incidents where the wire has broken, and that the materials of the wire are innocuous in the event a wire breaks. With vigorous exercise there have been reports of the wire breaking off subcutaneously when using thin wires (25 μm).

### 2.2.2.3 ELECTRODE LOCATION
The physiology and anatomical structure of the muscle are factors that need to be considered when using fine-wire electrodes. It is thought that the EMG signal recorded may not be reflective of the activity of the entire muscle due to the small recording area. This argument has been refuted however, as the bare ends of the wires can record signals from up to 300 microns away, and in this region the electrical potentials detected may come from at least 10 different motor units. Buchthal et al. demonstrated that fibers from up to 30 different motor units may be located within the same pick-up area of a needle or wire electrode. The literature indicates that motor units are widely dispersed within a muscle, and the ratio of type I to type II muscle fibers are similar throughout the muscle, suggesting that signals recorded from any area of the muscle should be reflective of the electrical activity of the whole muscle.

2.2.2.4 DETECTION REGION

There are a few factors to consider when using fine-wire indwelling electrodes. The use of indwelling electrodes is limited due to the cost of the electrode, its invasive nature, and subject discomfort during insertion. Specialized training is also a necessity for persons using intramuscular electrodes. It is nearly impossible to determine the position of the electrodes once they are inserted into the muscle belly without the use of magnetic resonance imaging (MRI) or the use of real time ultrasound imaging to guide the insertion. The high variability observed in quantifying the EMG amplitude may in part be a function of the position of the electrode relative to the muscle fibers. The amplitude and frequency characteristics of the signal can be affected by the interelectrode distance which cannot be standardized using fine-wires. There is also evidence that electrode migration can occur after the indwelling electrode is embedded in the muscle. All of these factors can have a negative impact on reliability coefficients. Another consideration is the consistency of the pool of motor units that are within the recording area of the electrode which may change throughout a given testing session, and
definitely changes between testing sessions, despite careful electrode placement. Monitoring the placement of the intramuscular electrode throughout the testing session can be done using real time ultrasound however, this procedure is time consuming and once the wires are inserted the ability to make adjustments to the wires is limited, if not impossible.

When using wire electrodes it is important to recognize that inter-wire spacing and arrangement of the staggered wires once inserted is rarely known, despite their importance. Researchers must consider the influence of inter-wire spacing, wire diameter, and arrangement of staggered wires on frequency and amplitude characteristics for each application. Early studies reported that amplitude measures from the EMG signal recorded with fine-wire electrodes were reproducible. However, there have not been studies that have looked specifically at the reliability of fine-wire electrodes used to record electromyograms from the PFM. The difficulties encountered in electrode placement give rise to reliability issues when amplitude parameters are calculated from EMG data that were recorded using fine-wire electrodes. However, the use of fine-wires for determining onset and offset of muscle activation appears to be valuable, such as when examining muscle synergies during a pelvic floor muscle contraction.

2.3 MEASURING RELIABILITY

Reliability can be described in terms of consistency, reproducibility, and repeatability of a measurement. The extent to which a measurement is consistent (reliable) and free from error (valid) is fundamental to the interpretation of the results obtained when any instrument is used to measure physiological processes. When repeated measurements are taken from the same subject with the same instrument, a certain amount of variability is expected due to inherent
variability in subject performance, instrumentation and environmental noise. The observed measure is always the sum of the true score \(T\) and an error component \(E\):

\[
X = T \pm E
\]  

(1)

However, it is not possible to identify how much of the observed score is true and how much of it can be attributed to measurement or other error. One way to estimate this error is based on the amount of variance within a sample. The ratio of the true score variance to total variance (true score + error variance) is the basis for most reliability coefficients used in the literature, however, the true score is unknown.\(^\text{42}\) There are many types of reliability coefficients that can be calculated to quantify the reliability of measurements. Deciding which reliability coefficient to use will depend on the experimental design and intended purpose of the results.

Bland & Altman\(^\text{43}\) were the first to report the value in using the “limits of agreement” approach to compare two methods of measuring the same variable. This method defines both the difference in outcome score between two methods of measuring the same variable (measurement error) and the average outcome score of the two methods (estimate of the true value). The authors then plotted the difference between the measures against the mean of the two measures. Ninety-five percent limit of agreement lines \((\pm 2\) standard deviations of the difference scores\) are added to the plots to provide a visual representation of where the data lie relative to the estimate of the true score. One problem with this approach is that, when there is a large degree of variability between measures, the wide confidence interval for the mean difference will result in all data falling within the limits of agreement. As such, a measure of variability in the difference score, such as the mean absolute difference (MAD) should also be considered.
Correlation coefficients are used to identify associations between variables and can be used to quantify reliability when systematic error can be minimized such as when the same instrument or examiner is evaluating the same subject on separate occasions (test-retest reliability). Correlation coefficients fail to describe the degree of agreement between two measures, days, or raters, and only describe the relationship between the measurement outcome on the first occasion and the measurement outcome on the second occasion. If for example, there was a learning effect between measurement occasions, the correlation coefficient would fail to detect this. Within a group of subjects, the correlation coefficients will be high if subjects perform equally well relative to each other on both testing days and if the range of scores for the subjects are diverse. Pearson’s correlation coefficient is used for ratio and interval data that are normally distributed; whereas Spearman Rho is the non-parametric equivalent to the Pearson’s correlation coefficient but bases the coefficient on ranked data. It should be used with ordinal data and on data from small samples with non-Gaussian distributions. Due to the small sample size used in the current study, Spearman Rho values were used in assessing test-retest reliability.

The coefficient of variation (CV) is a unit free value derived by computing the ratio between the standard deviation of the measurements from a sample and the mean of the measurements from the same sample. It is often multiplied by 100 such that it can be reported as a percentage. The CV can be used to describe the variability within the measurements made with a particular instrument (or by a particular rater) and this variability can then be compared to that seen in other distributions when different measurement instruments or raters are used.

The stability of a response can be estimated by the standard deviation of the measurement error which is called the standard error of measurement (SEM). This statistical
measure is useful in test-retest reliability studies to determine the range of scores that would be expected from one test session to the next. This has important clinical implications when determining what change in score would reflect a clinically meaningful difference if applying these measures to a group receiving treatment or when trying to identify differences between groups.

Intraclass correlation coefficients (ICC) are widely used to describe reliability based on variance estimates calculated from an analysis of variance (ANOVA) model. ICCs were first used in the study of genetics and have been adopted by researchers in psychology and medicine. A variety of models and formulae are used in the literature to compute ICC, however, many papers discussing measurement reliability fail to identify which model was used and what the rationale was for choosing that particular model. Portney and Watkins describe three models based on work by Shrout and Fleiss. Model 1 is based on a one-way ANOVA, where as Models 2 and 3 are based on two-way ANOVAs. In the literature, authors have utilized both Model 2 and Model 3 to describe test-retest reliability. Muller & Buttner described a decision tree to guide researchers through using the best model based on their study design. The decision tree allows readers to choose the correct reliability model to follow based on the sampling theory of the study. Based on the decision model presented by Muller & Buttner and by Portney and Watkins, model 3 was used to calculate between-day and between-trial reliability of the EMG data in the current study. Each trial was included in the between-trial reliability calculation, therefore the model is denoted as model (3,1). For the between-day comparisons, the mean of three trials was computed prior to performing the analysis of variance and therefore the model is labelled model (3,k) or more accurately model (3,3). The instruments were chosen and not randomly selected, and each instrument was used independently to record EMG data from each subject participating in the study. The information
gleaned from these results cannot be generalized to other EMG detection systems used to record EMG activity from the PFM.

ICC models do not appear to be the most appropriate choice for this type of analysis, however, other researchers using similar instruments utilize ICC to quantify reliability and therefore the ICC values are presented here such that the results from the current study can be compared to the literature. The main problem with ICC is that they can over-estimate or under-estimate the true reliability of measurements based on whether the sample is highly heterogeneous or highly homogeneous respectively. When interpreting ICC to describe reliability, the reliability of the ICC is only significant if the subject main effect is significant, e.g. the subjects need to be different. When ICC reflect that the data are unreliable, one of three possible situations may exist: there is low variance within the sample of subjects, no correlation exists between the outcome variable and facet of interest (e.g. day, rater, trial), or a systematic bias within the facet of interest or set of subjects is present. As mentioned earlier, ICCs are calculated based on the variance estimates obtained from an ANOVA, however, the ANOVA uses group means to identify if any differences between measures recorded on one day were different from measures recorded on a second day. This method may fail to identify the amount of agreement or disagreement of subjects scores from day one and day two, even though the two distributions appear not to be statistically different.

When reliability coefficients are reported in the literature, arbitrary descriptions are often assigned to the value to give the reader some indication of “how reliable” the measure is. For example, Portney and Watkins report that a reliability coefficient of less than 0.50 suggest poor reliability, where as reliability coefficients between 0.50 and 0.75 and greater than 0.75 suggest moderate and good reliability respectively. Other authors have indicated that reliability
coefficients between 0.70-0.79 represent only fair reliability, 0.80-0.89 suggest good reliability, and reliability coefficients greater than 0.90 indicates high reliability. It is up to the discretion of the researcher to determine what reliability coefficient is appropriate given the purpose of the study. This arbitrary assignment can be misleading for readers when interpreting the results of reliability studies.

The repeatability of waveforms recorded from cyclical activity such as gait has also been described in the literature. A statistical measure called the adjusted coefficient of multiple determination (ACMD) can be calculated to describe the intra-subject variability within and between test sessions. Essentially, the ACMD is a ratio of variability within the day at a specified time (or between all days) to the total variability within the day (or among all days). The coefficient of multiple correlations (CMC) can then be calculated by taking the positive square root of the adjusted coefficients of multiple determination (CMD) in order to compare the repeatability of the waveforms. Another statistical measure used to assess repeatability of EMG data are variance ratios (VR), which can also be used in gait analysis to measure the repeatability of the shape of the waveform over a set number of cycles. The VR is a ratio of the mean square error between steps to the total sum of squares and can be used to measure repeatability of any waveforms over identical cycles. Unlike the other coefficients of reliability, a low variance ratio is indicative of a more reliable signal. Authors have used the VR to compare the reliability of surface and intramuscular electrodes to measure lower extremity muscle recruitment during gait.

2.4 RELIABILITY OF SURFACE AND FINE-WIRE ELECTRODE DATA

Reproducibility of EMG signals over multiple testing sessions can be improved by using anatomical landmarks that have been marked to guide the placement of surface electrodes. To
determine the optimal locations for recording surface EMG from the abdominal muscles, Ng et al.\textsuperscript{53} used a combination of bony landmarks and cadaver dissections to identify muscle fiber orientation and locations on the abdomen that minimized the overlapping of abdominal muscles. In a study to determine the ability of SEMG to detect feed-forward activation of the transversus abdominis and internal obliques (TrA/IO) muscle, Marshall and Murphy,\textsuperscript{54} reported high test-retest reliability (ICC 0.60 – 0.90, p<0.05) for their surface electrode placements. The electrodes are fixed on vaginal probes, therefore, placement from day to day should be consistent, unless the probes are not inserted with the same orientation relative to the muscles from day to day.

Many studies have been performed to test the reliability of different electromyographic techniques used to measure muscle function. There is evidence suggesting that the reliability of EMG data acquired when one controls for different muscles, different electrodes, different types of contractions (isometric and isotonic) and different contraction intensities is adequate. When guidelines are followed to maximize signal quality, the test-retest reliability (within day and between day) of EMG recorded from surface and indwelling electrodes is considered to be respectable (variance ratio < 0.30).\textsuperscript{51,52} There is a tendency for within day reliability (coefficient of multiple correlations (CMC) = 0.75-0.90, CV = 49-63%) to be slightly better than between day reliability (CMC = 0.61-0.88, CV = 50-73%).\textsuperscript{49} Pooling the results across studies appear to be limited by the variety of methods utilized for data acquisition, processing, and statistical analysis.

As mentioned previously, a key factor explaining why surface electrodes are favorable for use in research is their ease of application. Although variability in placement between recording sessions is a concern, guidelines are available which identify anatomical landmarks for placing
surface electrodes on most trunk, upper, and lower limb muscles to help optimize signal acquisition and minimize crosstalk, and to improve reliability. In a recent study by Ng et al, the test-retest reliability (between days) of data acquired using surface electrodes placed on six trunk muscles while subjects performed axial rotation at varying intensities were compared using ICC. Ten male subjects participated in the study. The protocol involved three testing sessions. On the first visit subjects became familiar with the equipment and procedures, on subsequent visits (separated by at least 7 days) data were recorded for analysis. EMG data were compared between days using the root mean square (RMS) values of EMG amplitude and median power frequency computed using the fast Fourier transform. The test-retest reliability of these parameters was found to range from good (ICC 0.75-0.89) to excellent (ICC ≥ 0.90) for all muscles. The high variability between days may be partly attributed to differences in volitional effort of the subject and discrepancies in positioning the electrode from day to day. In this study, reliability at lower contraction levels was no better than the reliability during maximal voluntary contractions.

In contrast, findings reported by Yang & Winter and Kollmitzer et al. indicate that reliability was better at lower contraction intensities (e.g. ≤ 50% MVC) compared to greater intensities (MVCs). Kollmitzer et al. found that the reliability coefficients were higher when a knee extension task was performed at 50% MVC (r = 0.97-0.99) when compared to the same task performed at 100% MVC (r = 0.67 – 0.93), when recorded from three different quadriceps muscles. This calls into question the ability of individuals to achieve a true maximal contraction as well as their ability to achieve consistent high intensity or maximal voluntary contractions.

Many reliability studies have been performed using surface and/or indwelling electrodes to evaluate muscle recruitment during gait. Because walking is a dynamic cyclic activity it is
useful to describe the repeatability of waveforms recorded during repeated cycles of walking. Kadaba et al.\textsuperscript{59} performed a comprehensive study to evaluate the repeatability of kinematic, kinetic, and EMG data recorded during the gait cycle in healthy adults (n=40). During the three test sessions that were one week apart, subjects performed three separate trials of walking over a set distance at a self selected pace. EMG data were recorded using bipolar surface electrodes placed over ten lower extremity muscles. The adjusted coefficient of multiple determination (ACMD) was calculated to describe the intra-subject variability within and between test sessions.\textsuperscript{49} The coefficient of multiple correlation (CMC) was then calculated. Overall, within day repeatability (mean of the ten muscles tested CMC = 0.84) was slightly greater than the between day repeatability (mean of ten muscles tested CMC = 0.81), but both values indicated good reliability.

In one study, EMG data were simultaneously recorded from surface and indwelling fine-wire electrodes in 5 lower extremity muscles while subjects (n = 10) walked at a self-selected pace over a 9 m runway.\textsuperscript{52} Kadaba et al.\textsuperscript{52} used the VR of the smoothed and rectified data to demonstrate that within-day reliability (multiple sessions of set trials were performed on the same day) using wire and surface EMG and found that the reliability was good (VR < 0.3). The VR (VR = 0.133 – 0.499) calculated from the surface electrodes was significantly (p < 0.01) less (i.e. better) than the VR (VR = 0.082 – 0.467) from the wire electrodes in most muscles except the tibialis anterior. Wire electrodes in the tibialis anterior muscle performed as good, or better, than the surface electrode in this location. The authors attributed this discrepancy to the unique characteristics of the tibialis anterior muscle such as the thin layer of skin overlying it, less bleeding upon insertion of fine-wires, less pain reported by the subjects, and less electrode migration detected throughout testing. Between-day reliability (defined as constancy in their study) was reported to be fair for surface electrodes (range of VR: 0.476 to 0.576) and poor for
wire electrodes (range of VR: 0.516 to 0.671). Within-day reliability coefficients were found to
be slightly higher than between-day reliability.

Bogey et al.\textsuperscript{51} demonstrated that test re-test reliability comparing surface and fine-wire
electrodes between days was not significantly different using the VR calculated from EMG data
recorded from the soleus muscle during gait ($p = 0.77$). The mean VR values for the surface
electrodes (VR=0.199) was found to be greater than the wire electrodes (VR=0.187) indicating
better reproducibility using fine-wire in the soleus muscle. The VR values reported for the wire
electrodes in Bogey et al.'s\textsuperscript{51} study were much lower than the values reported by Kadaba et al.\textsuperscript{52}
suggesting that reliability of the different electrodes could be dependent on which muscle is
being tested.

Giroux & Lamontage\textsuperscript{60} investigated the reliability (within- and between-day) of EMG
recorded simultaneously with surface and wire electrodes from three upper limb muscles during
isometric and dynamic conditions. Normalized EMG amplitude and integrated EMG were
compared between the two electrode types and there were no significant differences reported
between the two electrode types for within-day testing and under different conditions (dynamic
and isometric). Thus, there was a trend for between-day comparisons to be more reliable for the
surface electrodes ($r = 0.92$) when compared to wire ($r = 0.31$), but the differences were not
significant ($p > 0.41$). Amplitude values were less consistent than temporal pattern analysis,
both between-days and within-days.

In summary, there is a tendency for the reliability of surface electrodes to be greater
than that of fine-wire electrodes, especially between days. There is more room for error when
inserting fine-wire electrodes to a desired location (depth and location) within a muscle than
when placing surface electrodes on the skin. Wire electrodes also have the disadvantage of
recording from different motor unit pools due to variable factors such as inconsistent inter-electrode distances, the orientation of detection area to the muscle fibers, and electrode migration. Conversely, the effects of crosstalk contamination and the filtering effect of soft tissues between the muscle and electrode (when recording from surface electrodes) may contribute to decreased sensitivity of the electrode to detect subtle differences in test re-test conditions that are more easily detected with wire electrodes, and as such true differences in performance may be missed.

2.5 CROSSTALK

Contamination of the EMG signal with crosstalk from neighbouring muscles is a validity issue that must be addressed when using surface electrodes. In order to determine if there is crosstalk from other muscles, electrodes are placed on the muscle of interest and on nearby muscles. The peripheral nerves that innervate the nearby muscles are stimulated and the muscle of interest is monitored for increased EMG activation, which would suggest crosstalk is occurring. However, it is not possible to perform this task with the PFM. It is difficult to directly stimulate the pudendal nerve and lower sacral roots which activates the PFM without simultaneously stimulating the other muscles in the area with similar neural innervation.

Solomonow et al. determined that the amount of crosstalk that is recorded from surface electrodes is approximately twice the amount that is recorded when using fine wires; crosstalk accounted for less than 4-5% of the recorded signal amplitude when surface electrodes were used and only 1-2% when wire electrodes were used when recording from muscles in the lower leg. The authors concluded that this amount of signal inclusion from other muscles is virtually negligible for most biomechanical studies if guidelines for optimizing EMG recordings are followed (e.g. proper placement of the electrode away from the boundaries of the muscle).
In cases where subcutaneous adipose tissue is overlying the muscles (e.g. gluteus and abdominal muscles in most people), the authors state that EMG signals “are not reliable for scientific or clinical applications” (pg 141). They found that between 16 and 32% of the signal recorded with surface electrodes was crosstalk when a layer of subcutaneous fat was identified under the surface electrode. These results are specific to the muscles tested and cannot necessarily be generalized to other skeletal muscles.

Crosstalk must also be considered when using surface electrodes to record from smaller deeper muscles such as the soleus or PFM. Bogey et al.\textsuperscript{58} compared the normalized EMG recorded from indwelling wire electrodes positioned in two distinctly separate areas of the soleus muscle while simultaneously recording from surface electrodes placed near one of the wire recording sites during gait. The three EMG profiles (proximal wire, distal wire, and surface) had very similar timing characteristics and normalized amplitudes during the stance phase. However, during the swing phase activity was recorded in the surface electrode without detection by the indwelling electrodes indicating that the signal recorded from the surface electrode may have included myoelectric signals generated by muscles other than the soleus. Researchers must consider not only the reliability of the EMG signal acquired from the different electrodes, but also the validity. When using surface electrodes that are embedded on vaginal probes, crosstalk issues must be explored further.

2.6 PELVIC FLOOR MUSCLES

2.6.1 PFM ANATOMY

The caudal region of the pelvis can be divided into two primary layers composed of a combination of muscle and connective tissue – a superficial layer that has important sexual functions and a deep layer that provides support for the abdominopelvic organs and is a key
component of the continence mechanism. There are conflicting reports in the literature regarding the nomenclature and subdivisions of the deep muscular layer of the pelvic floor. The deep muscular diaphragm can be divided into the coccygeus and levator ani muscles, and the levator ani muscle can be further divided into a superiolateral portion (iliococcygeus) and an inferomedial portion (puboviseralis, pubococcygeus, puborectalis, pubovaginalis). The deep PFM are positioned approximately 2.5 cm deep to the superficial perineal area. They are considered to be the muscles affected in women with pelvic floor dysfunction and during therapeutic exercise programs are the muscles of interest.

Even though the muscular portion of the pelvic floor includes of a number of distinct muscles with unique origins/insertions and fiber directions, it is accepted that the pelvic floor muscles function as a unit. As a group, the pelvic floor muscles contract concentrically in a combined ventral and cranial lifting action along with the bladder base. Singh et al. studied the anatomical positioning and movement of the pelvic floor using MRI during straining in 12 healthy, nulliparous women. They concluded that the iliococcygeus, which was found to have a medial slant with a cranial convexity on coronal sections, provided a supportive role and when contracted resulted in an upward lift. Using dynamic MRI to observe PFM movement and thickness during a voluntary contraction, Aukee et al. also found the iliococcygeus to be dome shaped at rest and to contract upwards enhancing the convexity during a PFM contraction. The study by Singh et al. also found that the more anteromedial portion, the puborectalis, was slightly thicker and moved in a dorsoventral direction to narrow the levator hiatus; which is thought to assist in maintaining continence. They speculated that the higher position of the iliococcygeus muscle may predispose it to trauma during the first stage of labor or during situations that increase intra-abdominal pressure (IAP). Likewise, the damage to the pelvic floor during second stage labor may preferentially affect the puborectalis muscle due to its position in
a lower plane. The vaginal probes used to record EMG data intravaginally are thought to detect activity primarily from the medial pubococygeus portion of the PFM.

Using ultrasounography, Bernstein\textsuperscript{66} found that the thickness of the right and left sides of the PFM were different in 9 healthy women. The right side was thicker than the left side of the PFM during rest ($p < 0.02$) and with a PFM contraction ($p < 0.02$). Bernstein\textsuperscript{66} also found that pelvic floor muscle thickness increased both at rest and during a PFM contraction, (7.6% and 9.3% respectively) after 6 months of PFM training in a group of 58 women with urinary incontinence. No side to side differences were reported before or after treatment. Aukeye et al.\textsuperscript{67} found that PFM EMG activation increased significantly ($p < 0.001$) after 12-weeks of PFM training. In a later study by Aukey and colleagues,\textsuperscript{65} a significant correlation between the EMG activation amplitudes recorded from the PFM using surface electrodes and thickness of the distal portion of the pubococygeus muscle was found when measured with dynamic MRI. Although the relationship was reported to be significant, the strength of the relationship was not remarkable (right PFM $r = 0.49$, and left PFM $r = 0.53$). They did however find a significantly reduced thickness ($p = 0.04$) of the distal pubococygeus muscle and EMG activation ($p = 0.03$) in women with urinary incontinence as compared to a group of asymptomatic women. Another interesting finding by Aukeye et al.\textsuperscript{65} was the observation that in 5 of the 16 subjects, the perineal body deviated either to the right or to the left during a PFM contraction, suggesting asymmetrical activation or force produced by the right and left sides of the PFM. A similar observation was made by Constantinou et al.\textsuperscript{68} During a voluntary PFM contraction, the vagina was displaced asymmetrically in 15 out of 28 subjects when MRI images of the pelvic area were examined. An overview of studies that used ultrasound, MRI, and EMG analysis to describe the dimensions, movement, and recruitment of the PFM indicates that there is strong potential for
asymmetries in the PFM. Researchers/clinicians should evaluate each side of the pelvic floor independently until conclusive evidence suggests otherwise.

### 2.6.2 FUNCTIONAL ANATOMY

The PFM contribute to spinal stability, maintaining continence, and regulating intra-abdominal pressure, as well as contributing to postural and respiratory functions. It is well known that the PFM work in synergy with the trunk muscles. These important functions are at risk of being compromised if the performance of the PFM and their synergists fail. Assessing the PFM’s ability to contract and quantifying the force generated by the contraction can help to identify the impairment and direct treatment. It is important to establish that a healthy functioning muscle requires the proper neuromuscular input (timing and force gradation), the ability to generate force (appropriate length tension relationship, contractility, flexibility), and the endurance to resist premature fatigue.

The PFM functions both as a postural muscle with tonic activity to give support to the pelvic organs, assist in breathing, and the help maintain continence as well as a phasic muscle as it responds to rapid changes in IAP. Histological investigations have confirmed that the PFM are made up of 67% slow twitch and 33% fast twitch muscle fibers, with a notable amount of connective tissue interspersed within the muscle. Kinesiological EMG studies have identified three common patterns of activity in the pubococcygeus muscle in both continent and incontinent women. Women demonstrated either continuous firing of motor units at rest (tonic activity pattern), absence of regular motor unit activity (phasic activity pattern), or in some cases prolonged but not sustained motor unit activity (intermediate activity pattern). Interestingly, in healthy nulliparous women Deindl et al. observed that women with the “tonic
activity pattern” demonstrated a more gradual recruitment of motor units and that those with “phasic activity” showed a brisk recruitment pattern.

2.6.3 CLINICAL ASSESSMENT OF THE PFM

Assessment tools are available that test the ability of the PFM to contract and measure the force that they can produce. Digital palpation is one of the easiest, most efficient, cost effective, and portable methods available to trained professionals for assessing pelvic floor muscle function. The reliability of digital palpation has been documented using a variety of assessment protocols and grading systems. Inter-examiner and test-retest reliability was high ($r > 0.70, p < 0.05$) using the PERFECT scheme to assess pelvic floor muscle function. When the validity of the PERFECT scheme was tested, the results indicated significant positive correlations between digital assessment and perineal lift ($r = 0.864, p = 0.031$) and digital assessment and maximum pressure recorded using an intravaginal manometer ($r = 0.786, p < 0.001$). Perineal lift was measured using a weighted vaginal probe with a plastic extension positioned alongside a ruler to observe cranial movement of the rod. A number of other studies have found dynamometry and perineometry to be reliable measures of PFM strength.

EMG is often used to study pelvic floor muscle function, particularly with the aim of studying urinary incontinence in women. Activation of the PFM during elevation of IAP has been cited as an important factor contributing to increasing urethral pressure to assist in maintaining continence, contributing to approximately one third of urethral closure pressure. Surface EMG recordings from the PFM have been found to correlate with intravaginal pressure generation, ($r = 0.73$). In a large group of older women ($n = 388$), Brink et al. demonstrated a positive correlation between maximum EMG amplitude and digital assessment ($r = 0.60, p < 0.01$). Mayer et al. found a weak to moderate correlation ($r = 0.28$ to
0.74, p < 0.05) between EMG amplitude and digital assessment of PFM strength. However, Mayer et al.\textsuperscript{76} failed to report how the EMG data were acquired (sampling rate, amplification, filtering), what electrode configuration/shape/size was used, what signal processing was done, and how the PFM EMG amplitude values were calculated. A consistent and disappointing observation in the literature is the neglect of many researchers to give adequate information regarding the acquisition and analysis of EMG data obtained from the PFM. Given the potential for misleading results and the number of intrinsic and extrinsic factors that affect signal reliability and validity it is surprising that more care is not taken to ensure the quality of signal detection and the clarity of reporting in this area.
2.6.4 RECORDING EMG FROM THE PFM

2.6.4.1 SURFACE ELECTRODES

An early study by Lose et al. studied the striated urethral sphincter muscle using surface electrodes placed on a small sponge and positioned in the vagina to record the electromyographic activity from the anterior vaginal wall in 8 subjects. Qualitative similarities between the recorded signals were identified while EMG activity was simultaneously acquired from the urethral sphincter using needle and surface electrodes. This is one of the earlier studies that used intra-vaginal surface electrodes to record from the striated muscles within the pelvis. The authors concluded that intra-vaginal surface electrodes could provide researchers with a simple and reliable technique to record EMG activity from the striated urethral sphincter. However, their study did not include any quantitative measures, and is therefore of limited use in research applications.

There are a number of challenges that face researchers when recording electromyographic activity from the PFM. Not only are they located in a sensitive area, they are also deep within the pelvic cavity, and many healthy individuals are unable to volitionally contract the PFM properly. Bo et al. found that 32% of women with stress urinary incontinence performed PFM exercises incorrectly. The most consistent muscle substitutions included straining (pushing down) the PFM or through contracting the extra-pelvic muscles such as hip adductors and gluteal muscles. The PFM function synergistically with the TrA muscle. Bo et al. found that 30% of their healthy female subjects depressed their pelvic floor instead of elevating it during a TrA contraction, suggesting the PFM were not strong enough to withstand the increase in IAP during the abdominal maneuver. For any study that investigates the function
of the PFM an internal exam should be performed on each subject to describe the movement of the PFM during a voluntary contraction to determine their recruitment pattern.

Researchers have attempted to reduce the invasiveness of pelvic floor muscle EMG evaluation by using surface electrodes on the perineum instead of intravaginal probes. Workman et al.\textsuperscript{83} looked at the relationships between EMG activity recorded during PFM contractions from surface electrodes placed on the perineum and the intravaginal pressure generated using a fluid filled pressure sensor. EMG signals that are detected by placing surface electrodes on the perineum include the combined electrical activity from all the muscles within the detection area of the electrodes. This may include activity from the hip adductors, hip rotators, hip extensors, the superficial PFM, and hopefully the deep PFM. To control for the variability in EMG activity recorded from each subject due to differences in muscle mass, adipose tissue, and effort, Workman et al.\textsuperscript{83} first transformed their raw data into z-scores. A significant relationship was identified between sEMG and intravaginal pressure $r = 0.75$ (p < 0.01).

Using surface electrodes to record EMG data from the PFM is a challenge due to the deep location of the muscles within the pelvis. Vaginal probes with electrodes embedded on the external surfaces have been used by researchers to reduce the distance between the detection surface and PFM membrane.\textsuperscript{3,9-11,17,20,84,87-90} The advantages of this particular design are two-fold. Patient comfort can be improved as the vaginal probes are often easily inserted by the subject and in most cases, the subject can remain clothed for most of the experimental procedures. Firstly, subject comfort is important in terms of ethics, for subject recruitment, and to create an environment that minimizes extrinsic factors that may bias the data (e.g. the effect of pain from the instrumentation on EMG amplitude is unknown). Performance of some tasks
such as a maximal contraction can be influenced by patient comfort. A true maximum may not be achieved because of pain, likewise, additional muscles may be activated if the patient is anxious or feels that the probe is going to slip out. Secondly, detecting the myoelectrical activity closer to the surface of the deep PFM has the potential to give the researchers valuable information for quantitative analysis while controlling for the filtering effect on the signal traveling through multiple layers of soft tissue, thus decreasing crosstalk.

On the other hand, the use of vaginal probes does not come without a number of considerations. As described in detail above (Section 2.2) the orientation of the detection surfaces mounted on the probes with respect to the muscles fibers will have a significant effect on the signal properties. Therefore the geometry of the probe deserves attention. The amount of muscle stretch/elongation that occurs as the probe is inserted into the vaginal canal is dependent on the size and shape of the probe relative to the anatomy of the individual women. The amount of deformation that occurs is variable among women, and to date, the influence of PFM length/tension on EMG signal characteristics is unknown. Force that is generated by skeletal muscle contraction is influenced by the length of the muscle fibers (length-tension relationship). The optimal sarcomere length for a given muscle is the point at which the overlap of actin and myosin gives rise to the highest force generation. The amount of force produced will be lower when the sarcomeres are too short or too long. The PFM behave no differently. Morin et al. discovered that when force produced by the PFM was measured using an instrumented speculum with varying aperture widths, women (continent and incontinent) produced higher peak force values as the diameter of the dynamometer increased (p < 0.001), increasing significantly from the 0.5 cm to 1.5 cm aperture opening. This suggests that force production may be enhanced using devices placed intra-vaginally, therefore muscle activation
amplitudes detected using vaginal probes may overestimate the amplitude of the contraction when the vaginal diameter is optimized by the diameter of the probe.

The recording surface shape (e.g. circumferential, oblong) and configuration (monopolar or bipolar) also influence the signal characteristics. The Femiscan™ vaginal probe (Figure 2-1) is configured to record a differential signal from each side of the PFM with bipolar pairs of electrodes on either side, whereas the Periform™ vaginal probe (Figure 2-2) acquires signals independently from each side of the pelvic floor with two single monopolar detection surfaces.
Some vaginal probes that are used for electrical stimulation, biofeedback, and for research have a ring type electrode that records activity circumferentially.\textsuperscript{77,93} Although this type of electrode is adequate when used for muscle stimulation, the myoelectric signal detected is a crude composition of all the electrical activity produced in the area, therefore lacking specificity. Regardless of how the EMG signal is acquired from the right and left side of the pelvic floor, it is common for authors to report only one value (usually amplitude). When reporting only one value, it is important for authors to describe their methods clearly, which has not been done sufficiently in the literature. These practices are problematic as the muscles on either side of the pelvic floor are different muscles – they have separate origins and insertions and their own neural and vascular supply, as was described previously. Using a multiple-electrode surface EMG array Azpiroz et al.\textsuperscript{12} found that the puborectalis muscles had bilateral innervation as well as identified innervation zones in the lateral fascicles of each of the muscles when examined from the anal canal. Findings such as this have not been reported for the more anteriorly positioned portion of the PFM. Recording a common signal decreases the specificity of the signal, making it
difficult to identify abnormal recruitment. The extent to which side-to-side differences contribute to pelvic floor dysfunction is currently unknown.

The dimensions of the recording surfaces are variable for different vaginal probes making it difficult to compare characteristics of the electromyographic signals. Detection surfaces that have a larger surface area will result in larger EMG signal amplitudes and may increase the susceptibility of picking up crosstalk.

As previously mentioned, the position of the electrode relative to the muscle fibers can directly affect the amplitude of the signal. While using EMG amplitude as an outcome variable, positioning of the probe can influence the variability of the signal, especially when changing positions and during repeated test sessions. The placement of the probe into the vagina is often done by the subject which might influence where contact is made between the muscle fibers and recording surface if the position of the probe is not validated by the researcher. Bo et al.\textsuperscript{64} confirmed the placement of the vaginal pressure sensor used in their study and only included trials of PFM contractions where the sensor was observed moving inwards to ensure that the subjects were not straining or recruiting other muscles. Confirming the positioning and movement of any vaginal measurement device is strongly encouraged to enhance the reliability and validity of the measurement.

2.6.4.2 PFM FINE WIRE ELECTRODES

Intramuscular fine-wire electrodes are an under-utilized technique that can be used to measure electromyographic activity of the PFM and has been recommended for use during scientific research.\textsuperscript{94} Once the wires are inserted and the cannula removed, the wires allow pain free recording without interference from bulky vaginal probes or concern for changes in the length tension relationship of the pelvic floor muscles that may bias the recording. The wires
essentially create an experimental condition that closely mimics the natural state of the pelvic floor muscles during voluntary and reflex contractions. Manufacturers claim that once the wires are in place there is little chance for them to become dislodged.

Indwelling wire electrodes have been used by a handful of researchers to study the pelvic floor muscles. Deindl et al.\textsuperscript{4} used fine-wire EMG to evaluate the activity patterns of the right and left pubococcygeus muscles in a sample of healthy nulliparous women performing a number of voluntary and reflex contractions. In this study they observed bilateral recruitment of the muscles, identified individuals with tonic PC activity at rest and those with phasic patterns of activity. Later, they went on to compare the healthy control subjects to a group of parous incontinent women and found that 50\% of the women with SUI demonstrated asymmetrical recruitment of the PC muscle.\textsuperscript{8}

\subsection*{2.6.5 RELIABILITY OF EMG DATA FROM THE PFM}

An early study by Thorp et al.,\textsuperscript{93} was designed to establish normative values for electromyographic activity of the PFM using an acrylic plug with surface electrodes attached circumferentially around the probe. To assess the test-retest reliability of the instrument used in this study, they randomly allocated 8 of their 41 subjects to return for repeat testing (39-122 days apart). The subjects performed an unreported number of short fast contractions (flickers) and slower longer contractions (holds - 10 second), first with a smaller anal probe and secondly with a larger vaginal probe. The EMG activation amplitude was calculated and compared between trials. Within-day reliability was reportedly high; ICC ranged from 0.89 to 0.96 for both the vaginal and anal plug. Although the ICC suggest very good within-day reliability, when the coefficients of variations (CV) are calculated using their reported means and standard deviations, a great amount of variability was identified: the CV was 41.5\% and 47.5\% for the
vaginal flick and vaginal hold tasks respectively. The ICC values that were calculated each day between trial were then correlated to describe the test-retest reliability. The correlation coefficients ranged from $r = 0.76$ to $r = 0.97$, suggesting that the EMG values were reproducible between test sessions however, correlation coefficients fail to identify agreement of the EMG values between test sessions and only measure the relationship between two variables. The author’s failed to report the number of repetitions/trials for each task and the methods employed to extract quantitative information from the EMG signal was poorly described.

The Periform™ vaginal probe (Figure 2-2) has been used in many studies to record EMG data from the PFM, for clinical use as a biofeedback device, and for electrical stimulation of the PFM. Thompson et al. compared PFM EMG activation amplitudes recorded one week apart in five of their study participants ($n = 13$) and reported excellent reliability, ICC$_{2,3} = 0.98$ with a standard error of measurement (SEM) of 0.06. The SEM represents the range of scores that can be expected when subjects are retested, a smaller value is indicative of greater reliability. Another popular vaginal probe available for research and clinical use by Femiscan™ (Figure -2-1). As this probe was being developed, Aukee et al. compared the EMG activation amplitudes and between-trial reliability of four slightly different vaginal probes during PFM MVCs performed in supine ($n = 11$). EMG data were acquired separately from the left and right sides of the PFM. Side to side differences were not addressed in the study, however, a review of the descriptive data provided (range and mean of the EMG amplitudes) suggest that the activation amplitudes of left and right sides of the PFM were different. The authors comment that although the sample size was too small to claim that the sides were statistically different, there appeared to be a difference in EMG amplitude recorded from the left and right sides of the pelvic floor across all subjects ($MAD = 9.0 \pm 8.4 \mu V$). Between trial reliability was assessed
using Spearman rho correlation coefficients and a strong association between trials was identified ($\rho = 0.84$ to $0.97$, $p < 0.05$).

Surface EMG recorded from the pelvic floor was reported to have good test re-test reliability using a single-user vaginal surface EMG sensor manufactured by Thought Technology. The device consists a longitudinal surface electrode mounted on either side of a plastic probe, the signals were acquired as a bipolar differential signal (the differential was taken between the left and right side of the PFM, which is not a valid approach). The purpose of the study was to determine the reliability and clinical predictive validity of surface electrodes for measuring PFM EMG. Subjects (n=37) were required to perform a series of assessment tasks (Glazer Pelvic Muscle Assessment Program) with the probe in situ on separate days. The EMG amplitude calculated from the PFM was compared between test days using Pearson’s correlation coefficients where a strong significant relationship between test days ($r = 0.86$, $p < 0.001$) was found. Again, agreement cannot be assumed from the statistical test employed.

A publication by Santiesteban in 1988, identified high variability in the amount of integrated EMG that was recorded intra-vaginally between subjects (pregnant and non-pregnant women). The vaginal probe used in this study was bar-bell shaped and had three detection surfaces embedded on the side walls. The description of the data acquisition procedures was vague.

Reliability measures are not frequently reported in the literature when fine-wire electrodes are used to record EMG data from the PFM. Excellent intra-subject reproducibility of EMG patterns recorded across trials in the pubococcygeus muscle has been documented in both the supine and standing positions. However there were no statistical analysis performed to substantiate these claims.
2.6.6 VALIDITY AND CROSSTALK STUDIES IN PFM EMG

Vaginal probes are designed to allow surface EMG recordings from the PFM that lie deep within the pelvis while maintaining subject comfort and dignity. While using surface electrodes to record the EMG activity of muscles that lie deep to the superficial muscles, crosstalk can be a significant disadvantage. The question of crosstalk from muscles that are adjacent the PFM muscles should be thoroughly addressed by researchers when using vaginal probes to record surface EMG from the PFM.

While using a vaginal probe containing two surface electrodes Santiesteban,\textsuperscript{95} separately tested five non-pregnant subjects to determine if their recording surfaces were picking up crosstalk. The subjects tested were able to isolate a PFM contraction without a simultaneous increase in EMG activity recorded from the hip abductors, hip adductors, hip extensors, and lower abdominal muscles. However, when subjects were required to resist isometric hip abduction and hip adduction, a sevenfold and tenfold increase, respectively, in the integrated EMG was detected, suggesting that crosstalk was recorded from neighbouring muscles. Using concentric needle EMG, Bo & Stein\textsuperscript{79} sought to identify the relationship between the pelvic floor muscles and striated urethral wall muscles during isometric contractions of the abdominal, hip abductor, hip adductor, and hip extensor muscles. Even when using the concentric needle, which records from a localized area within the muscle belly, contraction of the hip abductor, adductor, and extensors muscles all gave rise to an increase in EMG activity recorded in the PFM and striated urethral wall muscle, suggesting that the PFM may actually be contracting in response to hip muscle activity. The PFM also contracted in response to the abdominal muscle activation tasks, whereas the urethral wall muscle did not. Peschers and co-workers\textsuperscript{78} completed an interesting study evaluating four different methods that are commonly
used to assess PFM strength; perineal ultrasound, digital palpation, intravaginal surface EMG, and pressure perineometry. In supine, the subjects (n=16) were required to perform nine different contraction tasks (isometric contractions of the PFM, abdominal muscles, hip adductors, gluteal muscles, and a Valsalva – plus the last four tasks with a simultaneous PFM contraction). Increases in PFM EMG activity and intravaginal pressure were evident during isolated contractions of the abdominals, hip adductors and during the Valsalva maneuver, as well, PFM EMG increased during the gluteal muscle contraction. Interestingly, no change in bladder neck position was observed with perineal ultrasound during the isolated contractions, suggesting that the changes detected in pressure generated and PFM EMG amplitude originated from muscles other than the pelvic floor. It is well recognized that bladder neck elevation has been identified during PFM contractions when using standardized techniques.96-98

The Periform™ vaginal probe has been used in a number of studies.3,9-11,16,31 Authors have claimed that the signals recorded by the Periform™ are free from crosstalk.10 However, reports of crosstalk (or the absence of crosstalk) are not adequately addressed in the literature, and are even misleading. Surface electrodes are often positioned on nearby muscles (e.g. hip adductors, gluteal muscles) while subjects perform a PFM contraction – observing for changes in hip adductor/gluteal muscle activation.10 However, the reverse would give more valuable information. Subjects should perform isometric contractions of the nearby muscles while the observer identifies any changes in EMG activity recorded by surface electrodes near the PFM. This practice is also problematic in that the extent to which the PFM engage synergistically to help stabilize the pelvis during these manoeuvres is unknown. Sapsford & Hodges10 clearly state that PFM EMG activity increases consistently with increased effort during abdominal muscle activation tasks – and the amplitude during the maximum abdominal effort is no different than the amplitude observed during a PFM MVC. In addition, when the subjects were instructed to
relax the abdominal muscles in standing, there was a subsequent decrease in PFM EMG activity, further supporting our view that this method of recording from the PFM requires further investigation. The detection surfaces on the Periform™ probe are large relative to the size of the PFM and are configured to either record two independent monopolar signals or a differential signal subtracting the signals recorded from the right and left sides of the pelvic floor. Combining the two sides to obtain a differential signal is still questionable due to the large interelectrode distance (2.5 cm). To differentiate between a signal originating solely from the PFM and a signal containing crosstalk, simultaneous recordings using fine-wire intramuscular electrodes and the different probes will give valuable information regarding the extent of crosstalk present.

The evidence appears to be sufficient to conclude that using surface electrodes which are embedded on some type of vaginal probe appear to be very susceptible to crosstalk contamination from nearby muscles. With respect to EMG, many of the aforementioned papers do not give sufficient detail to evaluate the quality of EMG signal recorded from the PFM. There needs to be more specific information regarding what type of electrode configuration was used, what acquisition system was used, what the amplifier specifications were, and more detail on signal processing methods.

After describing the possible evidence suggesting how susceptible the vaginal detection surfaces are to crosstalk, there is another plausible explanation for the observed findings. The PFM may be activated to help stabilize the pelvis during the resisted tasks or work synergistically with other muscles around the pelvic girdle. Using intramuscular fine-wire electrodes to record from the abdominal muscles (TrA, IO, EO, and RA) in seven women, Hodges et al. studied abdominal muscle activation in response to PFM contractions in three different lumbar spine
positions. In addition, fine-wire electrodes were inserted into the right pubococcygeus muscle transvaginally (n = 2) to record PFM activity during three tasks involving abdominal muscle activation. Unfortunately the sample included just 2 subjects and one of the subjects was unable perform the abdominal manoeuvres correctly. In the remaining subject, activation of the PFM above baseline was observed during the abdominal tasks with amplitudes of between 36 and 97% of maximum voluntary electrical activation (MVE). In a recent publication by Hodges et al.\textsuperscript{16} the crosstalk evaluation entailed recording EMG activity from the PFM using the Periform™ probe while also recording EMG from a number of extra-pelvic muscles. This time, the subject (n = 1) was required to contract the extra-pelvic muscles at an intensity that equalled the intensity that they would be activated at during the experimental tasks, while consciously trying to relax their pelvic floor muscles. Naturally, they found no change in PFM activity with the low level contractions of the extra-pelvic muscles. Although this suggests the absence of crosstalk when using the Periform™ while these muscles contract at the lower intensities, it fails to support the hypothesis presented earlier that the PFM may be recruited to help with pelvic stability. Co-activation of the PFM and abdominal muscles has been supported in other studies,\textsuperscript{3,9,15,79,87} but these also suffer from methodological concerns.

The specificity and validity of the recorded signal is questionable. An investigation (n=2) to examine the position of different vaginal probes relative to the puborectalis muscle with MRI and US imaging was completed by Voorham-van der zalm et al.\textsuperscript{2} It was determined that the recording surfaces of the Periform™ vaginal probe was not in contact with the puborectalis muscle. The width of the probe appeared to push the vaginal wall and PR muscle aside such that the electrodes on the probe were sitting below the level of the muscle, therefore registering a composite signal from all the surrounding muscles (including responding to changes in IAP).
2.6.7 EFFECTS ON PFM EMG PARAMETERS

As stated previously, the pelvic floor muscles have a role in supporting the abdomino-pelvic organs. Intuitively, the amount of support provided by the pelvic floor should be greater in standing compared to the supine position due to the effects of gravity. Bo and Finckhagen, measured the difference in resting pressure, maximum squeeze pressures, and holding time in supine and standing of the pelvic floor muscles using a fiberoptic microtip transducer connected to a balloon catheter (Camtech) positioned in the lower vagina in 18 urinary incontinent women. No significant differences were observed in maximum pressure generation or holding time (p=0.884 and p=0.409 respectively) between the two positions. However, there was a lower resting pressure measured in the supine (29.1 cmH2O) compared to the standing (37.7 cmH2O), p<0.001, positions. Most researchers assess the function of the PFM in the supine position for a number of reasons; the ease of standardizing patient position, convenience for both the researcher and the subject, instrumentation limitations, and patient comfort and dignity. In terms of urinary incontinence however, most women report episodes of leaking occurring in the upright position, not the supine position.

Using surface electrodes on a vaginal probe, Santiesteban found a five-fold increase in integrated EMG activity at rest when subjects moved from supine to standing. The study was investigating differences in EMG activity and strength of the PFM in different postures between pregnant and non-pregnant women. Similarly, resting EMG activity was found by Shafik et al. to be significantly (P < 0.05) higher in standing (98.7±11.2 μV) when compared to supine (73.4±10.9 μV) using a concentric needle to record from the mid-posterior levator ani muscle.

Using indwelling electrodes to record EMG activity from the PFM during a number of tasks, Deindl et al. concluded that recordings were consistent regardless of test position (supine
versus standing), this was also the case in a later study comparing a group of healthy women to a group of women with stress urinary incontinence.  

2.7 CONCLUSION

Given the limited availability of reliability measures for PFM EMG in the literature the current study was undertaken to address this need. To provide a comprehensive reliability analysis three different EMG devices were tested; the Periform™, the Femiscan™, and fine-wire electrodes. These devices were selected based on their appropriateness, meaning that separate EMG signals could be recorded from the right and left sides of the PFM. The devices were tested for reliability of EMG amplitude data recorded at rest, during a maximum voluntary PFM contraction, and during a cough. These tasks were performed in both supine and a standing position.
3.1 RESEARCH QUESTIONS

The following questions were addressed in this study:

1. Are amplitude, signal to noise ratio, and baseline activity comparable between the left and right sides of the PFM with the Femiscan™, the Periform™ or fine-wire electrodes?
2. What is the between-trial reliability of each recording electrode and how do they compare?
3. What is the test-retest reliability of each recording electrode and how do they compare?

3.2 RESEARCH DESIGN AND SUBJECT SELECTION

A single sample, repeated measures study design was implemented to determine the test-retest reliability of three different electrodes used to record electromyographic signals from the PFM. A convenience sample 12 healthy nulliparous women between the ages of 19 and 40 years were recruited from Queen’s University by word of mouth. Individuals were excluded if they reported having any previous gynecological surgeries, a history of pelvic organ prolapse, were pregnant or had previously given birth, had greater than one episode of stress urinary incontinence in any given week, or had any neurological conditions known to influence muscle activation for EMG recording.

3.3 SUBJECT SCREENING AND MEDICAL HISTORY

The study received ethics approval from the Queen’s Research Ethics Board (REH-315-06) (see Appendix I for details). Subjects were screened in person to rule out factors that would preclude them from participating in the study (see exclusion criteria listed above). The consent
form was reviewed with each subject by the investigator to ensure complete understanding of all aspects of the study prior to signing (Appendix II). Women who agreed to volunteer for the study participated in three separate evaluation sessions. Demographic data and brief medical histories were documented for each subject, including height and weight in order to calculate the body mass index (BMI). A short questionnaire that was developed to identify the presence and severity of any stress, urge, or mixed incontinence was completed by all participants. The details of the demographic information, medical histories, and incontinence questionnaire can be reviewed in Appendix III.

3.3.1 PHYSICAL EXAM

The physical exam visit included an assessment of pelvic floor muscle performance using digital palpation (Appendix IV). The physical exam was completed by an experienced physiotherapist who has been trained in the assessment and treatment of pelvic floor (dys)function. The internal pelvic exam was performed to rule out subjects with signs of pelvic organ prolapse, to observe the direction of pelvic floor movement with different tasks, and to assess the overall function of the PFM. The direction of pelvic floor movement was observed and documented during a cough, a voluntary PFM contraction, and while the subject performed a Valsalva maneuver (described as straining or bearing down). The position of the bladder neck and pelvic floor was palpated during a cough and during a PFM contraction to evaluate the direction of movement of each structure during the task. Manual muscle testing of the PFM was used to assess the strength of the combined squeeze and elevating action of the pelvic floor muscles as a group, with the performance graded using the modified Oxford scale. This scale was found to have good inter- and intrarater reproducibility as reported by Peschers et al. cited from the PhD thesis of Laycock. In addition to manual muscle testing, a more detailed
assessment of the PFM was performed using digital palpation. The PERFECT scheme, developed by Laycock,\textsuperscript{72} which has been tested for reliability and recently modified,\textsuperscript{102} was used to identify recruitment patterns and to assess PFM contractility, strength, and endurance using tasks that are similar to the tasks being evaluated in the EMG portion of the study (Appendix V). Details of the evaluation can be found in Appendix VI. The data collected to answer the questions specific to this thesis are part of a larger study. During all tasks, EMG activation of four different abdominal muscles was recorded. The electrode locations can be viewed in Appendix VII.

### 3.4 EMG TESTING

The EMG assessment was completed on two separate occasions in order to investigate the test-retest reliability of the different types of electrodes. Ideally, 7-14 days between test sessions was chosen to minimize the effects of learning, allow for any soft tissue damage from the indwelling electrodes to heal, and to minimize any changes in the subject that would influence the EMG signal. Three subjects had to reschedule their appointments when they were unable to participate while menstruating. Each EMG session lasted approximately 2 hours including subject instrumentation. The actual testing lasted no more than 60 minutes. To standardize bladder fullness, immediately prior to testing all subjects were instructed to void. The testing procedure was thoroughly described to the subjects prior to starting each session to ensure they were familiar with all the tasks.

To minimize discomfort during the insertion of the fine-wire electrodes into the PFM, Xylocaine 5%, a topical anesthetic was applied generously to the area between the labia majora and pubic rami bilaterally. At this time the examiner palpated the perineum to identify landmarks for the wire insertion. To assess the ability of each subject to voluntarily contract the pelvic floor muscles the examiner also palpated the surface of the perineum while the subject...
was asked to contract the PFM and to cough lightly. Subjects that were unfamiliar with PFM contractions were educated at this time on the anatomical location and function of the pelvic floor as well as given standardized instructions on how to properly contract their PFM. While waiting for the topical anesthetic to take effect, each subject was taught how to use the Peak Flow Meter (Figure 3-1), which measured the peak expiratory flow generated during the coughing task. The subjects were required to cough into the peak flow meter while their nose was sealed using nose plugs. The peak flow generated was measured by reading the velocity of peak flow (litre per minute) as indicated by the marker which was forced through the meter. The peak flow meter was used to measure the consistency in peak flow generated during the coughs between sessions. The subject practiced using the peak flow device until three consistent recordings were obtained (± 30 L/min).

![Figure 3-1: Peak Flow Meter](image)

PFM EMG was recorded using three different detection systems. The indwelling electrodes used for this study were paired stainless steel hooked-wire electrodes (Calgren Enterprises, Inc., Gilroy CA. 221-28SS-730). The fine wires were inserted with a 27 gage (30mm) hypodermic needle into the left and right anterior pubococcygeus muscle midway between the pubic symphysis and ischial tuberosity, approximately 1 cm medial to the pubic rami. The needle
was inserted in a cranial-medial direction to a depth of between 2 and 2.5 cm (depending on the resistance felt in the needle and the size of the subject). Using ultrasound imaging the width of the puborectal portion of the PFM has been reported to be 2.5 cm.\(^2\) Counter pressure was applied at the point at which the needle penetrated the skin as the needle was withdrawn, leaving the hooked-wires embedded in the muscle belly. The subjects were then asked to perform a series of 6-10 PFM contractions to help embed the hooked wires into the PFM and reduce the amount of electrode migration after initiating data collection.\(^{103}\) The wires were then taped to each inner thigh and the loose ends were connected to the amplifier by a spring-wire coil connector (Appendix VII see circle #5).\(^{104}\) The signals acquired from each PFM were sampled at 4000Hz, amplified 10,000X, bandpass filtered 20 – 2000Hz, and stored on a personal computer for later analysis.

Surface EMG signals were recorded using two different vaginal probes. The Femiscan™ Probe (Mega Electronics Ltd., Savilahdentie 6, P.O. Box 1750, 70211 Kuopio, Finland) is an L-shaped probe with six longitudinally placed stainless steel electrodes evenly spaced around the probe (Figure 2-1). The detection surfaces are 5.8 cm in length and 0.3 mm wide with an interelectrode distance of 10 mm. The Femiscan™ probe was designed for clinical assessment and biofeedback treatment purposes. The Femiscan™ records signals independently from each side of the pelvic floor using a bipolar configuration. The detection surfaces on the anterior and posterior aspects are designed to be used as internal references, when used with the custom software that it was constructed for. In our lab, an external reference electrode (left ASIS) was used for both channels. The differential signals were pre-amplified (200X) and relayed to the main EMG amplifiers to provide an overall gain of 1000.
The second surface electrode system was the Periform™ vaginal probe (Neen, vaginal probe). Like the Femiscan™, this is also a commercially available vaginal probe that is used in treating pelvic floor muscle dysfunction. It has dual functions; it is used as a biofeedback device for clinical assessment and treatment and also has electrical stimulation capabilities. The Periform™ (Figure 2-2) has only two recording plates that are 3.5 cm long and 1.5 cm wide (area = 5.25 cm² each) thus it records one signal from each side of the pelvic floor muscle. The probe has a circumference of 10 cm and is 7.5 cm in length. Each detection surface was coupled with a custom built monopolar lead (Delsys), referenced to the subjects ipsilateral iliac crest, and interfaced with the pre-amplifier and amplifier as described above. The signals that were acquired using the surface electrodes were sampled at 4000Hz, amplified 1000X and bandpass filtered between 20 and 450 Hz prior to being stored on a personal computer. For each surface electrode (right and left) EMG were recorded separately for analysis.

The order in which the electrodes were tested was quasi-random. The fine-wire data were always acquired first. This was done so that it was possible to record simultaneously from the surface and fine-wire electrodes during the later part of the session. The vaginal probes were randomly allocated to be tested second or third, and the order was consistent between testing sessions. All tasks were performed in both supine and in standing. While testing the fine-wire and Periform™ vaginal probe the tasks were performed in supine prior to standing. When the Femiscan™ was used, the tasks were performed in standing then in supine; this was done to minimize the number of position changes required by the subject, which would contribute to probe movement and potentially to subject discomfort.

For each detection system, four different tasks were performed in each position. Subjects were instructed to perform three PFM maximum voluntary contractions (pulling up and
in and squeezing), three single-barrel maximal effort coughs, and three straining maneuvers (Valsalva). Rest data were also recorded in each position before each task. EMG data were sampled over four seconds during the tasks. Subjects were given a minimum of 45 seconds rest between the MVC trials to minimize fatigue.

One reference electrode was positioned on the left ASIS which was used for the abdominal, intramuscular, and Femiscan™ electrodes.

3.4.1 INSTRUMENTATION

The EMG data were digitized using a 16-bit National Instruments A/D converter (PCI-MCIA-EIC), using a ±5V range, acquired using EMGWorks – Acquisition™ software (Delsys), and stored on a Pentium III personal computer for processing and analysis. Data processing was performed using Matlab™ v.6.5 and statistical analysis was performed in Minitab™ v.14 and GraphPad Prism™ 5.

The recording quality was assessed using visual inspection on a computer monitor during the recording sessions as well as afterwards using custom graphing software (Matlab™ v.6.5). Plots were excluded if they demonstrated signs of movement artifact, ECG contamination, or in the case of the intramuscular electrodes, if the fine wires appeared to have moved or fallen out of place during a position change. A signal to noise ratio (SNR) of 10 dB was arbitrarily assigned a priori as the minimum acceptable SNR; all files that had an SNR of 12 dB or less were carefully inspected for quality and were discarded if the EMG data were poor in quality.

Using a 100 ms sliding window with 99 ms overlap, EMG data were smoothed by calculating the root mean square (RMS) amplitude across each trial. The baseline activity levels were
defined as the 100 ms with the lowest RMS value during the trial. The baseline RMS value was removed from the maximum RMS value to compute the peak amplitude of the recorded signal for the cough and the MVC tasks. The SNR was calculated as the power of the signal divided by the power of the baseline activity, converted to decibels (dB). The peak EMG amplitudes recorded during the coughs were also normalized to the pelvic floor muscle MVC with the highest RMS amplitude for each subject and reported as a percentage of the maximum voluntary electrical activation (%MVE). Both raw and normalized amplitude data were analyzed.

3.5 STATISTICAL ANALYSIS

The test-retest reliability of PFM myoelectric activity was assessed for three different electrodes. For each instrument, four different tasks were considered: PFM MVCs in supine, PFM MVCs in standing, a cough in supine, and a cough in standing. For each task, test-retest reliability of the average peak EMG amplitude of three repetitions on each day, the signal to noise ratio, and the baseline activity were considered. Between trial reliability was assessed using the peak EMG amplitudes recorded from the three trials of each session, since amplitude is the measure most commonly reported in the literature. The alpha level was set at 0.05.

The following statistical analyses were performed:

3.5.1 ARE AMPLITUDE, SIGNAL TO NOISE RATIO, AND BASELINE ACTIVITY COMPARABLE BETWEEN THE LEFT AND RIGHT SIDE OF THE PFM WITH EACH RECORDING ELECTRODE?

Initially, a general linear model (GLM) was used for each instrument to determine if the peak EMG activation amplitude, signal to noise ratio (SNR), and/or baseline activity levels differed when recorded from the right as compared to the left side of the PFM during each task. During the cough tasks the normalized EMG activation amplitudes were also evaluated. The
average of three repetitions recorded each day was computed for comparison. The main effects of muscle, day, and the interaction between muscle and day were included in the model. Subject was included as a random effect in the model. When there was no significant interaction, this term was removed from the model. The difference between the right and left sides was reported as a percentage of the side with the larger activation amplitudes.

Next, the mean absolute difference (MAD) between the right and left sides for each subject was calculated for peak EMG amplitude, %MVE, and baseline activity (Equation 2). 95% confidence intervals (95% CI) for MAD were computed for each instrument, measure, and side.

\[
MAD_{ijkl} = \frac{1}{N} \sum_{i=1}^{N} \sqrt{(R_{ijkl} - L_{ijkl})^2}
\]  

(2)

Where \( N \) is the total number of subjects with acceptable data (mean of three trials per subject), \( i \) represents the \( i^{th} \) subject, \( Rt \) and \( Lt \) correspond to the RMS amplitude of the right and left side of the pelvic floor muscles, respectively. MAD were computed for each task \( (j) \), each instrument \( (k) \) and in each position \( (l) \). In order to compare the MAD among recording devices and tasks, the MAD was normalized to the average of the signal characteristics recorded from each side \( (nMAD) \).

### 3.5.2 WHAT IS THE BETWEEN TRIAL RELIABILITY OF EACH RECORDING ELECTRODE AND HOW DO THEY COMPARE?

To determine the consistency of the peak EMG amplitudes recorded between trials for each electrode, intraclass coefficients (ICC) were computed. Model \((3,1)\), as described by Portney & Watkins\(^{42}\) was determined to be the appropriate ICC (Equation 3). Subject and error mean square terms (BMS, EMS, respectively) were determined using a GLM with random effects subject and trial. \( k \) represents the number of trials that were performed for each task:
For each instrument, ICC’s were calculated for each side of the PFM within each day and for each task. The coefficients of variation (CV) between trials were also calculated for each subject (see equation 4). Within each day, the mean (± standard deviation) of the CV’s were calculated for each side of the pelvic floor. When no main effect of day was found, the results were pooled for each side of the PFM.

\[
CV = \frac{sd}{mean} \times 100, \quad (4)
\]

where \(sd\) is the standard deviation or square root of the variance and \(mean\) is the sum of the values divided by the number of trials.

Between trial reliability was compared between instruments by reporting the ICC and CV scores for each side of the PFM for each task.

3.5.3 WHAT IS THE TEST-RETEST RELIABILITY OF EACH RECORDING ELECTRODE AND HOW DO THEY COMPARE?

Between day reliability was assessed using a number of reliability measures. The mean of the three repetitions of each task was used for the between day analysis to reduce the variability attributed to between trial effects.

Spearman Rho, a non-parametric measure of the correlation between two variables, was also computed for the test-retest data.\(^{42}\) When the electrode type and subject remain the same between sessions, it is appropriate to use a correlation coefficient to determine the association between day one and day two values. The findings must be considered as a
correlation between variables, however, and not be assumed to represent the agreement between variables. A systematic bias can be identified by plotting the variables but is not reflected in the correlation coefficient. The correlation between the mean values reported for day one and day two were observed by plotting the data recorded on day one against that recorded on day two. Spearman Rho was reported and the significance level stated when the relationship was found to be significant.

A GLM was used to calculate subject, day, and error mean square terms which were then used to calculate the ICC $(3,k)$ using equation 5:

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

(5)

Where, similar to above, BMS represents the between subject variability, and the error variability is represented by EMS. The $k$ indicates that the ICC were calculated using the mean of a number of trials, which in this case $k = 3$. The mean of the three trials were used in the day to day comparisons and ICC were calculated separately for each instrument, side, and task. The MAD of peak amplitude, SNR, and baseline values between days was calculated for all of the instruments and for each condition. Similar to the equation used to answer question 1, in this case equation 5 was used,

$$ MAD_{ijkl} = \frac{1}{N} \sum_{i=1}^{N} \sqrt{(Day1_{ijkl} - Day2_{ijkl})^2} $$

(6)

where $Day1$ and $Day2$ refer to the values calculated for the variable being examined on day one and two respectively. $N$ refers to the number of subjects in the calculation and $i$ is the $i^{th}$ subject. The MAD was computed for each task $(j)$, with each instrument $(k)$, and in each position $(l)$. 
To determine if there were any differences in the variability between days among the different instruments, the MAD’s were normalized (nMAD) using the average of the two days (Equation 6). In this case the \( \text{MAD} \) is the mean absolute difference between the values reported on day one and day two and the denominator includes the mean of the values reported between the two days.

\[
\text{nMAD} = \frac{\text{MAD}}{\frac{\text{Day1} + \text{Day2}}{2}} \times 100
\]  

(7)
Chapter 4 RESULTS

4.1 SUBJECTS

Twelve nulliparous women between the ages of 24 and 40 (30.1±5.6 years) participated in the study. Height and weight were measured for all subjects to determine their body mass index (BMI). The mean BMI for the sample was 22.2±2.22 kg/m². The average length of time between test sessions was 11±5 days (range: 6–21 days). The physical exam was completed before the EMG assessment in 3 subjects, afterwards in 7 subjects, and between EMG test sessions in 2 due to scheduling conflicts.

4.2 DATA INCLUSION AND EXCLUSION

All EMG data files were carefully inspected using a custom built parameter verification program in Matlab™. EMG data files were visually examined for contamination from noise sources, motion artifact, and to verify that the automated parameter extraction program selected the appropriate values. As described in section 3.4.1, EMG data files were excluded when they failed to meet the appropriate standards. Example of some of the data files that were excluded are displayed in Figures 4-1 to 4-3, where time is on the x-axis in seconds and raw EMG amplitude is on the y-axis in volts (V). If a subject’s EMG data for a given task were usable on day one but data from that task were unusable on day two, data files from both days were excluded as this would have interfered with the test-retest reliability results.

The percentage of subjects whose data were usable is displayed in Table 1 according to each recording instrument and task. The percentage of subjects with useable data that were included in the analysis from the Femiscan™, Periform™, and fine-wires were 95%, 100%, and 60%, respectively. Femiscan™ data files were excluded from the analysis due to motion artifact,
having a SNR <10dB, and having noise interference evident on visual inspection. EMG data from ten of the twelve subjects were included in the analyses for all tasks, only the EMG data recorded from the left side of the PFM in one of these 10 subjects during the standing PFM MVC task had to be removed due to low SNR secondary to high baseline activity on that side. Only 60% of EMG data acquired using fine-wire electrodes was useable. The quality of the data recorded using the fine wires deteriorated as the testing session progressed; suggesting poorly embedded wires that were not resistant to migration during the frequent position changes or build-up of fluid due to tissue irritation at the site of the wire resulting in degraded acquisition. However, when the fine-wires remained in place, the electromyograms that were recorded from the PFM had high SNR values and distinct activation onsets. The majority of the fine-wire data files excluded were found to have low SNR values (perhaps a placement issue) or it was found that one or more wires became dislodged as the testing procedures progressed.

Figure 4-1: Example of motion artifact in PFM EMG signal when using the Femiscan™ vaginal probe during a cough

Figure 4-2: Example of low signal to noise ratio (SNR = 9.1 dB) when using fine-wire electrodes during a PFM MVC
Data from two subjects were removed completely from the analysis. Using palpation during the physical exam, it was identified that one subject was unable to perform a proper voluntary PFM contraction. On the manual muscle testing of the PFM this subject was graded a 1/5 on the modified Oxford grading scheme. In this same subject, during the EMG evaluation, PFM activation was not detected above baseline activity during the voluntary contraction when using the Femiscan™ and when recording with the fine-wire electrodes. Therefore, the data collected from this subject were excluded from the analysis.

One other subject was given a low score (2/5 on the modified Oxford) during a digital palpation exam during PFM contraction. There were a number of inconsistencies identified in her data and with each task this subject was found to be an outlier. Where this was most noticeable was in the data recorded from the left side of her PFM on day two, across all tasks. With such a small sample during the analysis process, it was found that across all instruments her values were driving the ICC and correlation values and therefore her data were excluded.

Table 4-1: Percentage of subjects with useable data from each instrument during each task

<table>
<thead>
<tr>
<th></th>
<th>Femiscan™</th>
<th>Periform™</th>
<th>Fine-Wire™</th>
</tr>
</thead>
<tbody>
<tr>
<td>MVC in Supine</td>
<td>100%</td>
<td>100%</td>
<td>80%</td>
</tr>
<tr>
<td>MVC in Standing</td>
<td>100%</td>
<td>100%</td>
<td>40%</td>
</tr>
<tr>
<td>Cough in Supine</td>
<td>90%</td>
<td>100%</td>
<td>70%</td>
</tr>
<tr>
<td>Cough in Standing</td>
<td>90%</td>
<td>100%</td>
<td>50%</td>
</tr>
</tbody>
</table>

Not including the EMG data from the two subjects who were excluded from all analysis. Maximum n=10
4.2.1 EASE OF USE AND COMFORT OF INSTRUMENTS

Subjects offered information regarding the ease associated with inserting the probes/fine-wires and their comfort (or discomfort) level during the evaluation process across instruments. Although there were no formal analyses planned or performed, the following themes were identified.

4.2.1.1 FEMISCAN™ AND PERIFORM™ VAGINAL PROBES

It was frequently reported that the Femiscan™ vaginal probe was easier to insert than the Periform™, however, subjects reported more discomfort when using the Femiscan™ throughout the test sessions because of the large base (Figure 2-1) which created a stretch of tissues at the introitus. Subjects also reported that probe movement was more noticeable with the Femiscan™ compared to the Periform™. During the MVCs, subjects reported sensing very little movement of the Femiscan™ probe, however, during coughing (especially in standing) the subjects frequently reported the sensation of the probe sliding caudally at which time they felt they needed to reposition it or hold it in place using their hand. Subjects found that the Periform™, which has a slightly larger diameter at its widest point than the Femiscan™, was not inserted as easily, but once it was in place subjects felt that it was more comfortable than the Femiscan™ and allowed for position changes without sensing that the probe position was altered. The shape of the Periform™ probe, which narrows at both ends but is wide in the middle, tended to remain seated within the vagina without as much motion and without inducing such a stretch on the tissues at the introitus.

4.2.1.2 INDWELLING ELECTRODES

Subjects entered the study with pre-conceived ideas regarding the invasiveness and potential discomfort associated with the insertion and use of fine-wire electrodes. During the
insertion of the fine wires, subjects complained of discomfort consistent with that experienced during inoculations. Once the fine-wires were inserted, the subjects commented that they could not feel the hooked-wires and described the discomfort that occurred during the insertion to be “less than what they had anticipated”.

4.3 ARE THE AMPLITUDE OF THE MVC AND COUGH DATA COMPARABLE BETWEEN THE LEFT AND RIGHT SIDES OF THE PFM WITH EACH RECORDING ELECTRODE?

Comparisons of the EMG signals recorded from the right and left sides of the PFM were inconsistent among subjects and instruments as described in detail below.

Figure 4-4: EMG amplitude between the right and left sides of the PFM during PFM MVC in Supine

4.3.1 FEMISCAN™ VAGINAL PROBE

Overall, the analysis suggests that with the Femiscan™ detection system, the left and right sides of the PFM generate different RMS amplitudes. Both day one and day two data were pooled for each side for the analysis after it was determined that there were no significant differences between days for any of the variables (p >.24).
4.3.1.1 RMS AMPLITUDE OF BASELINE ACTIVITY

In supine, there was a trend suggesting that the RMS of the baseline EMG activity before the MVCs were performed was 21% higher on the left side compared to the right side (p = 0.06). In the baseline activity recorded before the cough, the EMG amplitude was also higher (17%) on the left side as compared to the right, but again the difference was not statistically significant (p=0.12) (Tables 4-2 and 4-3). The RMS of the baseline activity recorded in the standing position was found to be significantly higher on the left side of the PFM compared to the right both before the MVC (27%, p=0.006) and before the cough (31%, p = 0.01).

A more direct evaluation of the magnitude of the individual differences in baseline activity recorded from both sides of the PFM was to calculate the mean absolute difference for each subject. Overall, there was a 1.3 and 2.4 μV difference in baseline RMS amplitude between the left and right sides of the pelvic floor in supine and standing respectively, in the MVC task. The MAD of the RMS amplitude of the baseline recorded on the right and left side of the pelvic floor before coughing was 1.7 to 2.1 μV in supine and standing, respectively. These values are only slightly higher than the expected instrumentation noise (<1 μV RMS).

4.3.1.2 RMS AMPLITUDE DURING THE PFM MVCS

During the PFM MVC tasks the peak RMS amplitudes recorded from the left side of the PFM were 19% (supine) and 17% (standing) higher in comparison to the right side of the PFM (p <0.05; Table 4-2). The MAD of the peak EMG amplitude recorded from the right and left sides of the PFM was 18.2 (13.7) μV in supine and 13.0 (12.6) μV in standing, the difference representing 41.4% and 32.8% of the mean signal amplitude (Table 4-2).
Table 4-2: EMG activity recorded from the left and right sides of the PFM during MVC’s using the Femiscan™ probe

<table>
<thead>
<tr>
<th></th>
<th>Supine</th>
<th></th>
<th>Standing</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>right mean(sd)</td>
<td>left mean(sd)</td>
<td>p-value</td>
<td>MAD nMAD</td>
</tr>
<tr>
<td>RMS amplitude (uV)</td>
<td>38.0(15.4)</td>
<td>47.0(19.2)</td>
<td>0.04*</td>
<td>18.2(13.7) 41.4%</td>
</tr>
<tr>
<td>Baseline RMS amplitude (uV)</td>
<td>3.0(1.6)</td>
<td>3.8(2.6)</td>
<td>0.06</td>
<td>1.3(1.3) 37.6%</td>
</tr>
<tr>
<td>SNR (dB)</td>
<td>23.7(6.3)</td>
<td>24.5(7.7)</td>
<td>0.42</td>
<td>3.1(2.2) 13.5%</td>
</tr>
</tbody>
</table>

**MAD** = mean absolute difference between right and left sides, **nMAD** = MAD normalized to the average of the right and left sides

* Denotes the EMG activity is significantly different between the left and right sides of the PFM. n = 10 for the RMS amplitude and SNR data both supine and standing. n = 9 for the baseline RMS amplitude data in both supine and standing.

4.3.1.3 COUGHING

Peak RMS amplitudes during coughing were similarly higher on the left side compared to the right side. Peak RMS amplitudes were 28% higher (p=0.009) on the left side compared to the right side of the pelvic floor when performed in supine and 22% higher (p=0.02) on the left side of the pelvic floor compared to the right side when performed in standing (Table 4-3). Although it appears that the peak EMG amplitudes were higher in the signals recorded from the left side of the PFM during the cough and MVC, once the cough data were normalized to each subjects MVC, no significant differences were found (Table 4-3). The normalized amplitudes recorded during coughing were very consistent between the sides of the PFM and in both positions (85.8%-88.6% MVE). When the MAD was normalized to the average of the signal amplitudes between the sides of the pelvic floor, a difference of 28.1% to 40.9% between the left and right sides during coughing in standing and supine respectively were found, which is similar to the values reported during the MVCs.
Table 4-3: EMG amplitudes during coughing recorded from the left and right sides of the PFM using the Femiscan™ probe

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<th>Supine</th>
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<th>Standing</th>
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<tbody>
<tr>
<td></td>
<td>right</td>
<td>Left</td>
<td>MAD</td>
<td>nMAD</td>
</tr>
<tr>
<td></td>
<td>mean(sd)</td>
<td>mean(sd)</td>
<td>p-value</td>
<td></td>
</tr>
<tr>
<td>RMS amplitude (µV)</td>
<td>29.7(12.7)</td>
<td>41.0(21.0)</td>
<td>0.009*</td>
<td>14.7(10.1)</td>
</tr>
<tr>
<td>%MVE</td>
<td>86.8(11.5)</td>
<td>88.6(6.5)</td>
<td>0.39</td>
<td>9.8(9.1)</td>
</tr>
<tr>
<td>Baseline RMS amplitude (µV)</td>
<td>2.8(1.8)</td>
<td>3.4(2.3)</td>
<td>0.12</td>
<td>1.7(1.2)</td>
</tr>
<tr>
<td>SNR (dB)</td>
<td>22.5(5.9)</td>
<td>23.6(7.4)</td>
<td>0.35</td>
<td>2.6(2.6)</td>
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</table>

MAD = mean absolute difference between right and left sides, nMAD = MAD normalized to the average of the right and left sides
* Denotes the EMG activity is significantly different between the left and right sides of the PFM. n = 9.

4.3.1.4 SIGNAL TO NOISE RATIO

No side to side differences were found in SNR across tasks (p > 0.05). The MAD between SNR computed for the left and right sides ranged from 1.2 dB (8.0%) during the standing cough task, up to 3.1 dB (13.5%) during the supine MVC.

Because significant differences between sides were found in the baseline, MVC, and cough data, the right and left PFM data were not pooled in the subsequent analyses as described below.

4.3.2 PERIFORM™ VAGINAL PROBE

The Periform™ vaginal probe records monopolar signals simultaneously from both sides of the PFM. Unlike the Femiscan™, the results suggest that the left and right sides of the PFM generate similar RMS amplitudes when the Periform™ probe is used to record EMG data. The RMS amplitudes (at rest, during the PFM MVC, and during coughing) were all higher than the RMS amplitudes recorded using the Femiscan™ vaginal probe.
4.3.2.1 RMS BASELINE ACTIVITY

Baseline activity was similar between the right and left side of the PFM during all tasks (Tables 4-4 and 4-5). The MAD between the EMG RMS amplitudes recorded at rest showed high variability in standing (MAD = 3.2 (6.9) to 3.4 (6.6) μV).

4.3.2.2 RMS AMPLITUDE DURING THE PFM MVCS

Peak EMG amplitudes during the MVC were found to be 22% higher in supine (p = 0.01) on the right side compared to the left side of the PFM when the Periform™ vaginal probe was used to record EMG data (Table 4-4). In standing, the right side of the PFM generated RMS amplitudes that were only 7% higher than the left side during the MVC, the difference was not significant (p = 0.59). The MAD between the peak EMG amplitudes was 46.2 (47.0) μV in supine (nMAD = 30.3%) and 25.8 (25.2) μV in standing (nMAD 20.2%). Like the Femiscan™, the nMAD between sides was 10% higher in supine compared to standing.

Table 4-4: EMG activity recorded from the left and right sides of the PFM during MVCs using the Periform™ probe

<table>
<thead>
<tr>
<th></th>
<th>Supine</th>
<th></th>
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<th></th>
<th>Standing</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>right</td>
<td>left</td>
<td>p-value</td>
<td>MAD</td>
<td>nMAD</td>
<td>right</td>
<td>left</td>
<td>p-value</td>
</tr>
<tr>
<td>RMS amplitude (μV)</td>
<td>158.6(84.1)</td>
<td>123.2(54.8)</td>
<td>0.01*</td>
<td>46.2(47.0)</td>
<td>30.3%</td>
<td>122.5(68.9)</td>
<td>113.8(65.0)</td>
<td>0.59</td>
</tr>
<tr>
<td>Baseline RMS amplitude (μV)</td>
<td>6.5(3.2)</td>
<td>7.4(3.5)</td>
<td>0.08</td>
<td>1.6(1.4)</td>
<td>21.4%</td>
<td>15.5(7.2)</td>
<td>17.7(10.3)</td>
<td>0.27</td>
</tr>
<tr>
<td>SNR (dB)</td>
<td>29.4(6.2)</td>
<td>27.0(7.9)</td>
<td>0.14</td>
<td>4.5(3.2)</td>
<td>16.1%</td>
<td>18.9(4.0)</td>
<td>17.5(4.1)</td>
<td>0.10</td>
</tr>
</tbody>
</table>

MAD = mean absolute difference between right and left sides. nMAD = MAD normalized to the average of the right and left sides. * Denotes the EMG activity is significantly different between the left and right sides of the PFM. n = 10.

4.3.2.3 COUGHING

There were no significant differences detected between the left and right sides of the PFM during the coughing tasks in supine or in standing (p >0.05) (Table 4-5). Consistent with the results reported when using the Femiscan™ probe, when the peak EMG amplitudes recorded
during the cough were normalized to the MVC, no significant difference between sides was found \((p>0.05)\). The normalized EMG amplitudes from the coughs were also consistent in supine and standing, 87.7 – 90.1% MVE and 87.9 – 88.7 %MVE, respectively. The normalized EMG amplitudes recorded using the Periform™ vaginal probe during the coughing tasks were similar to the normalized EMG amplitudes describe for the Femiscan™ vaginal probe in Section 4.3.1.3.

### Table 4-5: EMG activity recorded from the left and right sides of the PFM during coughing using the Periform™ probe

<table>
<thead>
<tr>
<th></th>
<th>Supine</th>
<th></th>
<th>Standing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>right mean(sd)</td>
<td>left mean(sd)</td>
<td>p-value</td>
</tr>
<tr>
<td>RMS amplitude</td>
<td>180.3(103.9)</td>
<td>151.8(58.3)</td>
<td>0.14</td>
</tr>
<tr>
<td>(\mu V)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%MVE</td>
<td>87.7(7.9)</td>
<td>90.1(6.5)</td>
<td>0.27</td>
</tr>
<tr>
<td>Baseline RMS</td>
<td>6.2(2.6)</td>
<td>6.8(3.1)</td>
<td>0.31</td>
</tr>
<tr>
<td>amplitude (\mu V)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SNR (dB)</td>
<td>30.7(6.3)**</td>
<td>29.7(7.9)**</td>
<td>0.75**</td>
</tr>
</tbody>
</table>

**MAD** = mean absolute difference between right and left sides, **nMAD** = MAD normalized to the average of the right and left sides

* Denotes the EMG activity is significantly different between the left and right sides of the PFM

** The SNR was different between days \((p=0.02)\) in supine, therefore, the difference between left and right sides were analyzed separately for each day, only the results of day two are displayed. \(n=10\).

#### 4.3.2.4 SIGNAL TO NOISE RATIO

Like the SNR calculated for the Femiscan™ vaginal probe, when the SNRs were computed for the signals recorded using the Periform™ vaginal probe no significant differences were identified \((p>0.05)\). In the supine position, the SNR calculated for the EMG data recorded on day two was 30.2 (6.7) \(\mu V\), however the SNR calculated on day one was 12% lower (26.5 (5.2) \(\mu V\)). The difference between days was significant \((p=0.02)\), therefore, SNR ratios were compared between the left and right sides separately for each day, with no significant differences identified between sides on day one or on day two \((p>0.05)\).
4.3.3 FINE-WIRE ELECTRODES

Fine-wire electrodes were inserted directly into the right and left sides of the PFM, minimizing crosstalk and allowing for very specific acquisition of electromyographic activity from each side of the PFM. EMG data were only included if a single subject had useable data from the left and right sides of the PFM on day one and/or day two. After excluding any EMG data files that were not appropriate for analysis (low SNR, motion artifact, incomplete data set), in supine eight subjects were included in the MVC analysis and seven subjects had EMG that could be used in the analysis of the cough data. In standing more data files had to be excluded, presumably resulting from wires becoming dislodged after the change in position. Four and five subjects had EMG that were useable in the analysis of the MVC and cough tasks respectively. Because of the low subject numbers with useable data included in the fine-wire analysis, the results from the statistical analysis were underpowered, therefore, for the EMG data recorded using the fine-wire electrodes a descriptive evaluation of the data is also presented. The results from the statistical analysis performed similar to the previous two devices are displayed in Tables 4-6 and 4-7.

4.3.3.1 RMS BASELINE ACTIVITY

The RMS baseline activity that was recorded on the right and left sides of the PFM before the MVC and coughing tasks were comparable between sides in both positions. There were no statistically significant differences between sides observed in the RMS amplitude detected at rest (p > 0.05). In fact, the MAD in PFM activation at rest was very small (0.5 – 0.6 µV) (Table 4-6).
4.3.3.2 RMS AMPLITUDE DURING PFM MVCS

Although a statistical difference was not identified between the RMS amplitudes recorded on the right and left sides of the PFM during the PFM MVCs (p >0.05), when the MADs were calculated, on an individual level the difference between the RMS amplitudes recorded on the right side were dramatically different from the signals recorded on the left side (nMAD 82.0 – 83.5%). The high standard deviations observed during the PFM MVCs reflect the variability within the sample.

Table 4-6: EMG activity recorded from the left and right sides of the PFM during MVCs using fine-wire electrodes

<table>
<thead>
<tr>
<th></th>
<th>Supine</th>
<th>Standing</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>right</td>
<td>left</td>
<td>p-value</td>
<td>MAD</td>
<td>nMAD</td>
<td>right</td>
<td>left</td>
<td>p-value</td>
<td>MAD</td>
<td>nMAD</td>
</tr>
<tr>
<td>RMS amplitude (μV)</td>
<td>72.6(50.6)</td>
<td>75.9(68.4)</td>
<td>0.86</td>
<td>58.5(41.0)</td>
<td>82.0%</td>
<td>57.5(38.9)</td>
<td>79.2(67.6)</td>
<td>0.15</td>
<td>45.9(39.6)</td>
<td>83.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline RMS amplitude (μV)</td>
<td>2.4(1.0)</td>
<td>2.2(0.7)</td>
<td>0.74</td>
<td>0.5(0.7)</td>
<td>18.0%</td>
<td>3.9(4.1)</td>
<td>2.5(0.7)</td>
<td>0.31</td>
<td>2.2(4.9)</td>
<td>32.9%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SNR (dB)</td>
<td>27.3(7.5)</td>
<td>28.4(6.7)</td>
<td>0.63</td>
<td>7.0(3.8)</td>
<td>26.5%</td>
<td>23.5(7.3)</td>
<td>26.9(9.3)</td>
<td>0.10</td>
<td>7.9(3.0)</td>
<td>34.8%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MAD = mean absolute difference between right and left sides, nMAD = MAD normalized to the average of the right and left sides. * Denotes the EMG activity is significantly different between the left and right sides of the PFM.
Supine: n = 8; Standing :n = 4.

4.3.3.3 COUGHING

The findings when RMS amplitudes were compared between the left and right sides of the PFM during the coughing task were similar to the differences observed between sides during the PFM MVCs when fine-wire electrodes were used to record EMG data. Interestingly, when RMS amplitudes calculated from the coughs were normalized, the %MVE was similar to those previously reported using the Femiscan™ and Periform™ vaginal probes (81-89 %MVE in supine and 85-86 %MVE in standing (Tables 4-3, 4-5, and 4-7).
Table 4-7: EMG activity recorded from the left and right sides of the PFM during coughing using fine-wire electrodes

<table>
<thead>
<tr>
<th></th>
<th>Supine</th>
<th>Standing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>right mean(sd)</td>
<td>left mean(sd)</td>
</tr>
<tr>
<td>RMS amplitude (µV)</td>
<td>70.4(63.8)</td>
<td>64.3(56.4)</td>
</tr>
<tr>
<td>%MVE</td>
<td>89.7(7.9)</td>
<td>81.5(18.1)</td>
</tr>
<tr>
<td>Baseline RMS amplitude (µV)</td>
<td>2.3(0.5)</td>
<td>2.4(0.7)</td>
</tr>
<tr>
<td>SNR (dB)</td>
<td>26.6(7.8)</td>
<td>26.1(7.5)</td>
</tr>
</tbody>
</table>

MAD = mean absolute difference between right and left sides, nMAD = MAD normalized to the average of the right and left sides
* Denotes the EMG activity is significantly different between the left and right sides of the PFM
Supine: n = 7; Standing: n = 5.

4.3.3.4 SIGNAL TO NOISE RATIO

The signal to noise ratios were very good when EMG data were recorded using the fine-wire electrodes (Range =22.5 to 26.9 dB). There were no significant side to side differences observed in SNR.

4.4 WHAT IS THE BETWEEN-TRIAL RELIABILITY OF EACH ELECTRODE AND HOW DO THEY COMPARE?

Peak EMG amplitudes generated from all trials and all tasks were plotted and visually inspected prior to statistical analysis. The results of the between-trial reliability assessment are presented in Figure 4-2, Figure 4-3, and Table 4-8. Overall each instrument showed good to excellent between-trial reliability. The EMG data were analyzed separately for each day of testing and for each side of the PFM, some of the data are reported as means between the two days of testing for the left and right sides of the PFM as indicated below.
4.4.1 FEMISCAN™ VAGINAL PROBE

The consistency between trials of RMS amplitudes generated by subjects and recorded by the Femiscan™ probe ranged from ICC(3,1) = 0.70 to ICC(3,1) = 0.98 during the PFM MVC. Overall the CV’s calculated from the MVC tasks were low (ranging from 8.5% to 14.2%), again indicating good consistency. There was a trend towards less consistency during the cough tasks when compared to the MVCs e.g. lower ICC’s and higher CV’s. On day one, the right side of the Femiscan™ had poor reliability (ICC = 0.61, CV = 20.7%); this could be attributed to one subject who had poor consistency between trials (e.g. RMS amplitudes during the coughs ranged from 8.1 μV to 40.4 μV), which might have been due to inconsistencies in performance or due to inconsistencies in probe position.

4.4.2 PERIFORM™ VAGINAL PROBE

Between-trial reliability was also good across all tasks when EMG data were acquired using the Periform™ vaginal probe (ICC(3,1) = 0.81 – 0.96). The CV’s ranged from 9.6% to 16.4% for the MVC task and from 10.6% to 19.5% during the cough task.

4.4.3 FINE-WIRE ELECTRODE

The indwelling electrodes demonstrated similar between-trial reliability across most tasks (ICC(3,1) = 0.77 – 0.99). The between trial reliability was poor during the cough task on the right side of the PFM on day one when fine-wires were used to record EMG data. Once again, one subject generated inconsistent EMG activation amplitudes between trials (37.1 – 126.5 μV), which for the small sample size, had a large influence on the ICC values. Although the ICC’s appear to be good when fine-wires are used, the CV indicate that intra-subject variability is higher than what was found with the other instruments (range of CV from 9.8 – 32.5%) (Table4-8). Like the Periform™, position and task did not influence the reliability coefficients.
4.4.4 COMPARISON AMONG INSTRUMENTS

As described above, the between trial reliability of all the detection systems was found to be good to excellent (displayed in Figures 4-5 and 4-6). The fine-wire electrodes demonstrated high between-trial ICCs on each side of the PFM (mean ICC(3,1)= 0.87 on the right and mean ICC(3,1)= 0.96 on the left) but also demonstrated large CVs (17.1% on both the right and left sides) suggesting that there is a large variability in fine wire EMG data from the PFM. The CV between trials when the Periform™ probe was used were 12.4% on the right and 14.8% on the left side of the pelvic floor and ICC(3,1)= 0.91 and ICC(3,1)= 0.90 for the right and left sides, respectively. The Femiscan™ performed equally as well as the Periform™ with CVs of 15.2% and 12.4% on the right and left sides, however the ICC values computed for the Femiscan™ were slightly lower than the Periform™, with ICC(3,1)= 0.80 on the right and ICC(3,1)= 0.86 on the left.

![Figure 4-5: RMS amplitude during PFM MVC in Supine](image)
Table 4-8: Between Trial reliability of the Femiscan™ and Periform™ vaginal probes and fine-wire electrodes

<table>
<thead>
<tr>
<th>Probe</th>
<th>Task</th>
<th>Right</th>
<th></th>
<th></th>
<th>Left</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ICC(3,1)</td>
<td>CV</td>
<td>ICC(3,1)</td>
<td>CV</td>
<td>ICC(3,1)</td>
<td>CV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Day 1</td>
<td>Day 2</td>
<td>Day 1</td>
<td>Day 2</td>
<td>Day 1</td>
<td>Day 2</td>
</tr>
<tr>
<td>Femiscan™</td>
<td>Supine MVC (n=10)</td>
<td>0.89</td>
<td>14.2(10.5)</td>
<td>0.96</td>
<td>13.6(12.4)</td>
<td>0.72</td>
<td>8.5(6.4)</td>
</tr>
<tr>
<td></td>
<td>Standing MVC (n=10)</td>
<td>0.74</td>
<td>11.7(5.4)</td>
<td>0.70</td>
<td>11.6(6.0)</td>
<td>0.82</td>
<td>12.7(9.2)</td>
</tr>
<tr>
<td></td>
<td>Supine Cough (n=9)</td>
<td>0.61</td>
<td>20.7(27.2)</td>
<td>0.84</td>
<td>17.0(10.8)</td>
<td>0.84</td>
<td>14.0(10.7)</td>
</tr>
<tr>
<td></td>
<td>Standing Cough (n=9)</td>
<td>0.79</td>
<td>15.7(10.6)</td>
<td>0.87</td>
<td>17.3(7.7)</td>
<td>0.86</td>
<td>14.9(11.8)</td>
</tr>
<tr>
<td>Periform™</td>
<td>Supine MVC (n=10)</td>
<td>0.90</td>
<td>12.9(9.2)</td>
<td>0.96</td>
<td>11.6(7.3)</td>
<td>0.87</td>
<td>9.6(6.3)</td>
</tr>
<tr>
<td></td>
<td>Standing MVC (n=10)</td>
<td>0.87</td>
<td>16.4(10.7)</td>
<td>0.95</td>
<td>13.6(9.0)</td>
<td>0.94</td>
<td>11.1(11.1)</td>
</tr>
<tr>
<td></td>
<td>Supine Cough (n=10)</td>
<td>0.93</td>
<td>19.5(10.8)</td>
<td>0.84</td>
<td>15.4(10.1)</td>
<td>0.91</td>
<td>12.4(10.3)</td>
</tr>
<tr>
<td></td>
<td>Standing Cough (n=10)</td>
<td>0.89</td>
<td>10.6(8.8)</td>
<td>0.90</td>
<td>18.3(10.1)</td>
<td>0.92</td>
<td>15.0(11.8)</td>
</tr>
<tr>
<td>Fine-Wire</td>
<td>Supine MVC (n=8)</td>
<td>0.94</td>
<td>12.3(10.8)</td>
<td>0.96</td>
<td>17.5(15.6)</td>
<td>0.96</td>
<td>11.5(10.1)</td>
</tr>
<tr>
<td></td>
<td>Standing MVC (n=8)</td>
<td>0.77</td>
<td>25.3(15.6)</td>
<td>0.92</td>
<td>18.8(14.5)</td>
<td>0.97</td>
<td>9.8(4.4)</td>
</tr>
<tr>
<td></td>
<td>Supine Cough (n=7)</td>
<td>0.94</td>
<td>12.1(7.4)</td>
<td>0.85</td>
<td>15.8(17.9)</td>
<td>0.94</td>
<td>32.5(36.4)</td>
</tr>
<tr>
<td></td>
<td>Standing Cough (n=7)</td>
<td>0.58</td>
<td>24.3(19.3)</td>
<td>0.99</td>
<td>8.4(9.0)</td>
<td>0.96</td>
<td>19.2(7.8)</td>
</tr>
</tbody>
</table>

CV represents the coefficient of variation and is reported as a % with the number in brackets denoting the standard deviation.
4.5 WHAT IS THE BETWEEN DAY RELIABILITY OF EACH ELECTRODE AND HOW DO THEY COMPARE?

Test-retest reliability was measured using three different statistical approaches: intraclass correlation coefficients (ICC), Spearman Rho correlation coefficients ($\rho$), and the mean absolute difference (MAD) between days. To allow comparisons of the overall reliability each probe, the MAD was normalized to the average of the responses on day one and day two. When the GLM was performed initially no day main effect was identified for any of the variables presented.

4.5.1 FEMISCAN™ VAGINAL PROBE

4.5.1.1 BETWEEN-DAY RELIABILITY OF THE RMS AMPLITUDE OF BASELINE ACTIVITY BEFORE THE MVCS AND BEFORE COUGHING

The RMS amplitude of the baseline activity recorded from the PFM using the Femiscan™ appeared consistent in supine when the raw data were inspected visually across tasks. Details of the calculations are displayed in Tables 4-9 to 4-10. The ICC and Spearman Rho coefficients were highly variable ranging from ICC(3,3) = 0.38 to 0.96 and from $\rho = 0.35$ ($p=0.36$) to 0.95 ($p<0.001$). The inconsistency of the ICC and Spearman rho coefficients is the result of inconsistent baseline EMG activity recorded from the left side of the PFM that is more obvious in standing.

4.5.1.2 BETWEEN-DAY RELIABILITY OF THE EMG AMPLITUDE RECORDED DURING THE PFM MVCS

Using the Femiscan™ probe the test-retest reliability was moderate to good when the EMG data were recorded form the right side of the PFM, with ICC(3,3)= 0.79 in supine and ICC(3,3)= 0.67 in standing (Tables 4-9 and 4-10). The between-day reliability on the left side of the PFM was not as high with the ICC(3,3)= 0.63 in supine and ICC(3,3)= 0.36 in standing. Similar results were found.
when the Spearman rho correlation coefficients were computed (ρ = 0.66 and 0.72, p<0.05 on the right and ρ = 0.22 and 0.48, p>0.05 on the left) in standing and supine, respectively. Also, in supine, the MAD of the RMS amplitudes between days for the MVCs were 9.3 (10.4) μV on the right and 15.6 (13.0) μV on the left side of the PFM. When the PFM MVCs were performed in standing, the reliability of the RMS amplitudes recorded on the right side (ICC(3,3) =0.67;  ρ =0.66, p = 0.04; MAD=7.4±6.1μV), appeared higher compared to reliability of the RMS amplitudes recorded on the left side (ICC(3,3) =0.36; ρ = 0. 22, p = 0.56; MAD=16.0±17.2μV) (Table 4-10) resulting in an overall determination that between-day reliability of this electrode is fair to poor.

**4.5.1.3 BETWEEN-DAY RELIABILITY OF THE EMG AMPLITUDE RECORDED DURING COUGHING**

Cough magnitude was monitored using a peak flow meter which records the peak expiratory flow generated during the cough. No statistically significant differences were identified in peak flow generation between days (p=0.24) while the Femiscan™ probe was used to record EMG data. The mean peak flow generated in standing (517.2±138.8 L/min) was found to be significantly higher than the mean peak flow generated in supine (453.9±141.3) (p<0.001).

The test-retest reliability results for the coughing task using the Femiscan™ vaginal probe are displayed in Tables 4-11 and 4-12. In supine, the test-retest reliability of the peak RMS amplitude recorded during the cough was poor on the right (ICC(3,3) =0.49) and moderate on the left (ICC(3,3) =0.70). In standing, the opposite was found, the ICCs were good on the right (ICC(3,3)=0.77) and poor on the left (ICC(3,3)=0.57). The RMS amplitude values did not correlate well between days in both supine and standing (p ≤ 0.55, p > 0.05). The MADs of the RMS amplitudes were lower in standing compared to supine, and when normalized to the mean RMS activation the MAD computed for the coughing task in standing represented less than 30% of
the total amplitude of the signal (Table 4-12). The ICCs and the Spearman rho correlation coefficients that were calculated for the normalized cough data were both low (ICC ≤0.30 and ρ≤0.09) in supine and standing, attributable to the low variability of scores within the sample (Figure 4-7). Again when all results are pooled, the overall reliability of non-normalized cough data is fair to poor, but normalized data are somewhat more reliable.

![Figure 4-7: Between-day comparisons of the normalized cough amplitudes performed in supine](image)

4.5.1.4 BETWEEN-DAY RELIABILITY OF THE SIGNAL TO NOISE RATIO

The SNR that was calculated for the EMG data recorded using the Femiscan™ vaginal probe was consistent between days (ICC = 0.73-0.96) across all tasks (Tables 4-9 to 4-12). When the PFM MVCs were performed in supine and in standing, the correlations between the SNR calculated on day one and day two were significant (ρ = 0.65-0.88, p <0.05) (Table 4-9). ICCs and correlation coefficients such as the Spearman rho can underestimate reliability when inter-subject variability is low, such as is observed in this case.
### Table 4-9: Between day reliability of PFM MVC EMG amplitude data when performed in supine and recorded using the Femiscan™ probe

<table>
<thead>
<tr>
<th></th>
<th>Day One</th>
<th>Day Two</th>
<th>MAD</th>
<th>nMAD</th>
<th>ICC</th>
<th>Spearman Rho (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMS Amplitude (µV)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>38.8(17.1)</td>
<td>37.2(14.4)</td>
<td>9.3</td>
<td>(10.4)</td>
<td>20.9%</td>
<td>0.79</td>
</tr>
<tr>
<td>Left</td>
<td>47.8(13.3)</td>
<td>46.3(24.5)</td>
<td>15.6</td>
<td>(13.0)</td>
<td>38.6%</td>
<td>0.63</td>
</tr>
<tr>
<td><strong>Baseline RMS Amplitude (µV)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>3.2(1.9)</td>
<td>2.8(1.3)</td>
<td>0.92(0.57)</td>
<td>29.4%</td>
<td>0.88</td>
<td>ρ = 0.85*, p=0.006</td>
</tr>
<tr>
<td>Left</td>
<td>3.9(2.8)</td>
<td>3.7(2.5)</td>
<td>1.3(1.1)</td>
<td>38.1%</td>
<td>0.89</td>
<td>ρ = 0.63, p=0.07</td>
</tr>
<tr>
<td><strong>SNR (dB)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>23.4(6.9)</td>
<td>24.0(6.2)</td>
<td>3.12(7)</td>
<td>14.9%</td>
<td>0.96</td>
<td>ρ = 0.88*, p=0.003</td>
</tr>
<tr>
<td>Left</td>
<td>24.7(8.2)</td>
<td>24.2(7.7)</td>
<td>2.0(1.8)</td>
<td>9.5%</td>
<td>0.93</td>
<td>ρ = 0.73*, p=0.03</td>
</tr>
</tbody>
</table>

*Denotes that the correlation is significant (p≤0.05). Reported values are means with the number in brackets representing standard deviation. Right (Rt) and left (Lt) side of the PFM had n=10 for the amplitude values and n=9 for the baseline and SNR values.

### Table 4-10: Between day reliability of PFM MVC EMG amplitude data when recorded in standing and recorded using the Femiscan™ probe

<table>
<thead>
<tr>
<th></th>
<th>Day One</th>
<th>Day Two</th>
<th>MAD</th>
<th>nMAD</th>
<th>ICC</th>
<th>Spearman Rho (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMS Amplitude (µV)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>35.6(7.6)</td>
<td>29.5(10.0)</td>
<td>7.36(6.14)</td>
<td>24.2%</td>
<td>0.67</td>
<td>ρ = 0.66*, p=0.04</td>
</tr>
<tr>
<td>Left</td>
<td>42.5(16.7)</td>
<td>34.5(19.6)</td>
<td>16.0(17.2)</td>
<td>42.8%</td>
<td>0.36</td>
<td>ρ = 0.22, p=0.56</td>
</tr>
<tr>
<td><strong>Baseline RMS Amplitude (µV)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>5.6(2.5)</td>
<td>4.8(2.4)</td>
<td>1.63(1.48)</td>
<td>30.3%</td>
<td>0.77</td>
<td>ρ = 0.65*, p=0.04</td>
</tr>
<tr>
<td>Left</td>
<td>8.1(3.1)</td>
<td>6.5(3.9)</td>
<td>3.07(2.95)</td>
<td>40.2%</td>
<td>0.49</td>
<td>ρ = 0.35, p=0.36</td>
</tr>
<tr>
<td><strong>SNR (dB)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>18.0(5.0)</td>
<td>17.7(4.5)</td>
<td>3.21(2.55)</td>
<td>18.4%</td>
<td>0.77</td>
<td>ρ = 0.65*, p=0.04</td>
</tr>
<tr>
<td>Left</td>
<td>16.7(5.6)</td>
<td>16.6(6.2)</td>
<td>2.05(1.84)</td>
<td>12.9%</td>
<td>0.95</td>
<td>ρ = 0.75*, p=0.02</td>
</tr>
</tbody>
</table>

*Denotes that the correlation is significant (p≤0.05). Reported values are means with the number in brackets representing standard deviation. Right (Rt) side PFM had n=10, and Left (Lt) side PFM had n=9.

### Table 4-11: Between day reliability of PFM EMG amplitude data when a coughing task was performed in supine and recorded using the Femiscan™ probe

<table>
<thead>
<tr>
<th></th>
<th>Day One</th>
<th>Day Two</th>
<th>MAD</th>
<th>nMAD</th>
<th>ICC</th>
<th>Spearman Rho (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMS amplitude (µV)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>27.6(10.7)</td>
<td>31.9(14.8)</td>
<td>10.7(11.0)</td>
<td>34.6%</td>
<td>0.49</td>
<td>ρ = 0.40, p = 0.29</td>
</tr>
<tr>
<td>Left</td>
<td>42.6(17.4)</td>
<td>39.4(25.1)</td>
<td>17.0(11.5)</td>
<td>47.6%</td>
<td>0.70</td>
<td>ρ = 0.45, p = 0.23</td>
</tr>
<tr>
<td><strong>% MVE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>86.4(14.7)</td>
<td>85.3(8.1)</td>
<td>11.2(9.91)</td>
<td>14.4%</td>
<td>0.30</td>
<td>ρ = 0.02, p = 0.98</td>
</tr>
<tr>
<td>Left</td>
<td>88.5(7.5)</td>
<td>88.7(5.8)</td>
<td>8.34(5.08)</td>
<td>9.3%</td>
<td>0.00</td>
<td>ρ = -0.10, p = 0.81</td>
</tr>
<tr>
<td><strong>Baseline RMS amplitude (µV)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>2.98(1.82)</td>
<td>2.55(1.89)</td>
<td>0.67(0.37)</td>
<td>28.4%</td>
<td>0.96</td>
<td>ρ = 0.95*, p &lt; 0.001</td>
</tr>
<tr>
<td>Left</td>
<td>3.58(1.85)</td>
<td>3.21(2.87)</td>
<td>1.90(1.13)</td>
<td>58.0%</td>
<td>0.73</td>
<td>ρ = 0.67, p = 0.06</td>
</tr>
<tr>
<td><strong>SNR (dB)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>21.2(4.3)</td>
<td>23.7(7.1)</td>
<td>3.00(5.00)</td>
<td>11.6%</td>
<td>0.73</td>
<td>ρ = 0.76*, p = 0.03</td>
</tr>
<tr>
<td>Left</td>
<td>23.4(6.6)</td>
<td>23.8(8.5)</td>
<td>4.02(3.39)</td>
<td>16.0%</td>
<td>0.87</td>
<td>ρ = 0.55, p = 0.13</td>
</tr>
</tbody>
</table>

*Denotes that the correlation is significant (p≤0.05). Reported values are means with the number in brackets representing standard deviation. Right (Rt) and left (Lt) side of the PFM had n=9.
Table 4-12: Between day reliability of PFM EMG amplitude data when a coughing task was performed in standing and recorded using the Femiscan™ probe

<table>
<thead>
<tr>
<th></th>
<th>Day One</th>
<th>Day Two</th>
<th>MAD</th>
<th>nMAD</th>
<th>ICC</th>
<th>Spearman Rho (ρ)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMS amplitude (uV)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>24.9(11.4)</td>
<td>23.8(11.4)</td>
<td>7.94(11.4)</td>
<td>31.6%</td>
<td>0.77</td>
<td>p = 0.55, p = 0.17</td>
</tr>
<tr>
<td>Left</td>
<td>32.7(12.4)</td>
<td>29.4(14.1)</td>
<td>7.47(12.6)</td>
<td>27.0%</td>
<td>0.57</td>
<td>p = 0.26, p = 0.54</td>
</tr>
<tr>
<td><strong>% MVE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>87.3(7.5)</td>
<td>86.1(6.8)</td>
<td>7.61(5.41)</td>
<td>8.6%</td>
<td>0.16</td>
<td>p = 0.09, p = 0.84</td>
</tr>
<tr>
<td>Left</td>
<td>86.5(9.4)</td>
<td>88.9(8.3)</td>
<td>9.95(8.40)</td>
<td>11.5%</td>
<td>0.00</td>
<td>p = -0.04, p = 0.93</td>
</tr>
<tr>
<td><strong>Baseline RMS amplitude (uV)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>4.95(2.27)</td>
<td>4.13(1.90)</td>
<td>1.12(0.72)</td>
<td>26.7%</td>
<td>0.96</td>
<td>p = 0.81*, p = 0.02</td>
</tr>
<tr>
<td>Left</td>
<td>7.29(3.11)</td>
<td>5.72(3.96)</td>
<td>3.31(3.11)</td>
<td>51.7%</td>
<td>0.38</td>
<td>p = 0.50, p = 0.22</td>
</tr>
<tr>
<td><strong>SNR (dB)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>16.1(4.6)</td>
<td>17.1(5.8)</td>
<td>1.94(1.25)</td>
<td>11.7%</td>
<td>0.94</td>
<td>p = 0.67, p = 0.08</td>
</tr>
<tr>
<td>Left</td>
<td>15.5(5.4)</td>
<td>16.9(6.1)</td>
<td>2.64(1.36)</td>
<td>17.1%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Denotes that the correlation is significant (p≤0.05). Reported values are means with the number in brackets representing standard deviation. Right (Rt) and left (Lt) side of the PFM had n=8.

4.5.2 PERIFORM™ VAGINAL PROBE

4.5.2.1 BETWEEN DAY RELIABILITY OF THE RMS AMPLITUDE OF BASELINE ACTIVITY THE MVCS AND BEFORE COUGHING

When the Periform™ vaginal probe was used, the reliability of the RMS amplitude of the baseline activity was found to be inconsistent between days across all tasks when the ICCs and Spearman correlations coefficients were determined (Tables 4-13 to 4-16). The ICCs ranged from ICC(3,3) = 0.24 to 0.87 and the correlation ranged from ρ = 0.25 to 0.90. These results may have been driven by outlying results from one or two subjects and/or by the homogeneity of the values recorded during the tasks.

4.5.2.2 BETWEEN DAY RELIABILITY DURING THE PFM MVCS

The ICC and correlation coefficients suggest good test-retest reliability using the Periform™ probe when PFM MVCs are performed in supine (Table 4-13). On the right side of the PFM the ICC(3,3) = 0.89 and ρ = 0.92 (p<0.001) and on the left side the values were still impressive, but not as high ICC(3,3) = 0.79 and ρ = 0.76 (p = 0.01.) Greater consistency was found in supine compared to standing when the Periform™ was used to record EMG during the MVC (Table 4-13 and 4-14).
During the PFM MVCs, the MAD of the RMS amplitudes between days recorded with the Periform™ was higher (37.3 – 59.1 μV) than the MAD between days using the Femiscan™ (7.4 – 15.6 μV). Normalized to the average amplitude of the signals recorded using the Periform™ however the MAD was less than 32% of the average amplitude of the data recorded in supine and between 35-40% of the average RMS amplitude of the data recorded in standing.

Based on the ICC values, the Periform™ appears to outperform the Femiscan™ in terms of reliability, however the MADs indicate that this may not in fact be the case.

4.5.2.3 BETWEEN DAY RELIABILITY DURING COUGHING

The peak flows generated during coughing with the Periform™ probe in situ on day one were not significantly different from the peak flows generated on day two (p = 0.10 in supine, p = 0.06 in standing). Consistent with what was found when peak flows were analyzed from the cough data using the Femiscan™, subjects produced peak flows that were 9% higher in standing compared to supine (p = 0.03).

During the cough task, the between day reliability of the RMS amplitude was variable between the sides of the PFM (Tables 4-15 and 4-16). The right side of the PFM demonstrated a significant correlation between day one and day two (ρ = 0.76, p = 0.01), and also produced a high ICC (ICC(3,3) = 0.94) when coughing was performed in supine. The left side was less consistent between days in supine when analyzed using the ICC and Spearman’s rho (ICC(3,3) = 0.42, ρ = -0.01, p = 0.99), however, the MAD between days was similar to that computed for the right side (35.6% right 37.3% left). When coughing was performed in standing, the left side showed more consistency between days (ICC(3,3) = 0.84, MAD = 47.5 ± 45.1 μV) compared to the right (ICC(3,3) = 0.68, MAD = 70.1 ± 77.1 μV). When Spearman’s correlation coefficients were computed, in standing both the right and left sides had a weak and insignificant relationships.
between day one and day two (\(\rho = 0.45-0.48, p>0.05\)), which suggests again that the test-retest reliability of the Periform\textsuperscript{TM} probe may not be any better than the Femiscan\textsuperscript{TM}.

### 4.5.2.4 SIGNAL TO NOISE RATIO

The between day reliability was inconsistent as well when the SNRs were compared from day one and day two using the traditional ICC and correlation coefficient methods (ICC\((3,3) = 0.22 – 0.74, \rho = 0.13 – 0.73\)). When the data were inspected further, the MAD (3.4 – 6.3 dB) and nMAD (15 – 23%) indicated low variability in the group which was reflected in an underestimation of reliability using the reliability coefficients that are based on variance ratios.

Table 4-13: Between day reliability of PFM MVC EMG amplitude data when performed in supine and recorded using the Periform\textsuperscript{TM} probe

<table>
<thead>
<tr>
<th></th>
<th>Day One</th>
<th>Day Two</th>
<th>MAD</th>
<th>nMAD</th>
<th>ICC</th>
<th>Spearman Rho ((\rho))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMS Amplitude ((\mu V))</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>144.3(66.8)</td>
<td>172.9(66.8)</td>
<td>40.4(44.3)</td>
<td>24.9%</td>
<td>0.89</td>
<td>(\rho = 0.92^*, p &lt; 0.001)</td>
</tr>
<tr>
<td>Left</td>
<td>119.4(45.5)</td>
<td>127.0(65.1)</td>
<td>37.3(27.4)</td>
<td>31.5%</td>
<td>0.79</td>
<td>(\rho = 0.76^*, p = 0.01)</td>
</tr>
<tr>
<td><strong>Baseline RMS Amplitude ((\mu V))</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>6.4(3.1)</td>
<td>6.6(3.4)</td>
<td>1.5(1.5)</td>
<td>24.3%</td>
<td>0.79</td>
<td>(\rho = 0.71^*, p = 0.02)</td>
</tr>
<tr>
<td>Left</td>
<td>7.4(3.1)</td>
<td>7.5(4.1)</td>
<td>2.4(2.0)</td>
<td>29.7%</td>
<td>0.75</td>
<td>(\rho = 0.58, p = 0.08)</td>
</tr>
<tr>
<td><strong>SNR (dB)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>29.9(5.8)</td>
<td>28.8(6.9)</td>
<td>4.3(3.8)</td>
<td>15.0%</td>
<td>0.74</td>
<td>(\rho = 0.65^*, p = 0.04)</td>
</tr>
<tr>
<td>Left</td>
<td>28.5(9.0)</td>
<td>25.5(6.8)</td>
<td>5.7(7.5)</td>
<td>20.1%</td>
<td>0.52</td>
<td>(\rho = 0.43, p = 0.21)</td>
</tr>
</tbody>
</table>

*Denotes that the correlation is significant (\(p \leq 0.05\)). Reported values are means with the number in brackets representing standard deviation. Right (Rt) and left (Lt) side of the PFM had n=10.

Table 4-14: Between day reliability of PFM MVC EMG amplitude data when recorded in standing and recorded using the Periform\textsuperscript{TM} probe

<table>
<thead>
<tr>
<th></th>
<th>Day One</th>
<th>Day Two</th>
<th>MAD</th>
<th>nMAD</th>
<th>ICC</th>
<th>Spearman Rho ((\rho))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMS Amplitude ((\mu V))</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>130.9(61.3)</td>
<td>128.9(79.3)</td>
<td>59.1(49.2)</td>
<td>42.2%</td>
<td>0.54</td>
<td>(\rho = 0.59, p = 0.07)</td>
</tr>
<tr>
<td>Left</td>
<td>119.8(73.7)</td>
<td>107.9(58.8)</td>
<td>48.2(52.6)</td>
<td>35.0%</td>
<td>0.58</td>
<td>(\rho = 0.72^*, p = 0.03)</td>
</tr>
<tr>
<td><strong>Baseline RMS Amplitude ((\mu V))</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>16.0(7.3)</td>
<td>17.2(6.9)</td>
<td>6.1(6.7)</td>
<td>34.8%</td>
<td>0.53</td>
<td>(\rho = 0.82^*, p = 0.004)</td>
</tr>
<tr>
<td>Left</td>
<td>15.7(5.6)</td>
<td>19.8(13.7)</td>
<td>5.8(7.9)</td>
<td>27.0%</td>
<td>0.77</td>
<td>(\rho = 0.90^*, p &lt; 0.001)</td>
</tr>
<tr>
<td><strong>SNR (dB)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>19.4(3.4)</td>
<td>18.4(4.4)</td>
<td>3.4(2.3)</td>
<td>18.8%</td>
<td>0.63</td>
<td>(\rho = 0.30, p = 0.40)</td>
</tr>
<tr>
<td>Left</td>
<td>18.1(3.4)</td>
<td>16.8(4.8)</td>
<td>3.4(2.9)</td>
<td>19.6%</td>
<td>0.60</td>
<td>(\rho = 0.17, p = 0.67)</td>
</tr>
</tbody>
</table>

*Denotes that the correlation is significant (\(p \leq 0.05\)). Reported values are means with the number in brackets representing standard deviation. Right (Rt) side PFM had n=10, and Left (Lt) side PFM had n=9.
**Table 4-15: Between day reliability of PFM EMG amplitude data when a coughing task was performed in supine and recorded using the Periform™ probe**

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
<th>MAD</th>
<th>nMAD</th>
<th>ICC</th>
<th>Spearman Rho (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMS amplitude (µV)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>168.2(115.3)</td>
<td>192.4(95.7)</td>
<td>44.6(29.9)</td>
<td>35.6%</td>
<td>0.94</td>
<td>p = 0.76*, p = 0.01</td>
</tr>
<tr>
<td>Left</td>
<td>130.7(53.8)</td>
<td>172.9(57.4)</td>
<td>52.5(58.8)</td>
<td>37.3%</td>
<td>0.42</td>
<td>p = -0.01, p = 0.99</td>
</tr>
<tr>
<td><strong>%MVE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>86.3(9.3)</td>
<td>89.0(6.3)</td>
<td>10.9(8.0)</td>
<td>12.7%</td>
<td>0.00</td>
<td>p = 0.50, p = 0.14</td>
</tr>
<tr>
<td>Left</td>
<td>90.0(7.6)</td>
<td>90.2(5.7)</td>
<td>6.7(4.3)</td>
<td>37.3%</td>
<td>0.38</td>
<td>p = 0.16, p = 0.65</td>
</tr>
<tr>
<td><strong>Baseline RMS amplitude (µV)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>6.0(3.0)</td>
<td>6.4(2.2)</td>
<td>1.8(0.9)</td>
<td>31.8%</td>
<td>0.82</td>
<td>p = 0.55, p = 0.09</td>
</tr>
<tr>
<td>Left</td>
<td>7.2(3.1)</td>
<td>6.5(3.3)</td>
<td>2.5(2.4)</td>
<td>35.9%</td>
<td>0.55</td>
<td>p = 0.25, p = 0.49</td>
</tr>
<tr>
<td><strong>SNR (dB)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>27.5(5.2)</td>
<td>30.7(6.3)</td>
<td>5.1(5.4)</td>
<td>17.8%</td>
<td>0.51</td>
<td>p = 0.15, p = 0.68</td>
</tr>
<tr>
<td>Left</td>
<td>25.9(5.3)</td>
<td>29.7(7.9)</td>
<td>6.3(5.0)</td>
<td>22.4%</td>
<td>0.22</td>
<td>p = 0.22, p = 0.53</td>
</tr>
</tbody>
</table>

*Denotes that the correlation is significant (p≤0.05). Reported values are means with the number in brackets representing standard deviation. Right (Rt) and left (Lt) side of the PFM had n=10.

**Table 4-16: Between day reliability of PFM EMG amplitude data when a coughing task was performed in standing and recorded using the Periform™ probe**

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
<th>MAD</th>
<th>nMAD</th>
<th>ICC</th>
<th>Spearman Rho (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMS amplitude (µV)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>146.6(65.6)</td>
<td>179.9(129.2)</td>
<td>70.1(77.1)</td>
<td>38.7%</td>
<td>0.68</td>
<td>p = 0.45, p = 0.19</td>
</tr>
<tr>
<td>Left</td>
<td>157.0(76.3)</td>
<td>153.1(63.3)</td>
<td>47.5(45.1)</td>
<td>26.9%</td>
<td>0.84</td>
<td>p = 0.48, p = 0.16</td>
</tr>
<tr>
<td><strong>%MVE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>90.7(5.8)</td>
<td>85.2(7.3)</td>
<td>7.6(5.9)</td>
<td>8.9%</td>
<td>0.40</td>
<td>p = 0.15, p = 0.70</td>
</tr>
<tr>
<td>Left</td>
<td>88.4(9.1)</td>
<td>89.0(9.9)</td>
<td>8.3(7.0)</td>
<td>9.6%</td>
<td>0.00</td>
<td>p = 0.01, p = 0.99</td>
</tr>
<tr>
<td><strong>Baseline RMS amplitude (µV)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>10.9(5.8)</td>
<td>12.7(8.8)</td>
<td>5.8(7.8)</td>
<td>39.0%</td>
<td>0.24</td>
<td>p = 0.59, p = 0.07</td>
</tr>
<tr>
<td>Left</td>
<td>10.4(2.6)</td>
<td>16.8(12.9)</td>
<td>7.0(10.9)</td>
<td>35.4%</td>
<td>0.42</td>
<td>p = 0.78*, p = 0.02</td>
</tr>
<tr>
<td><strong>SNR (dB)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>23.1(6.9)</td>
<td>23.5(6.0)</td>
<td>4.5(3.4)</td>
<td>20.3%</td>
<td>0.70</td>
<td>p = 0.52, p = 0.13</td>
</tr>
<tr>
<td>Left</td>
<td>23.5(4.90)</td>
<td>21.3(6.7)</td>
<td>4.3(3.8)</td>
<td>20.7%</td>
<td>0.73</td>
<td>p = 0.73, p = 0.21</td>
</tr>
</tbody>
</table>

*Denotes that the correlation is significant (p≤0.05). Reported values are means with the number in brackets representing standard deviation. Right (Rt) and left (Lt) side of the PFM had n=10.

4.5.3 FINE-WIRE ELECTRODES

4.5.3.1 BETWEEN DAY RELIABILITY OF THE RMS AMPLITUDE OF BASELINE ACTIVITY BEFORE THE MVCS AND BEFORE COUGHING

The results suggest that the test-retest reliability of the RMS amplitude of baseline activity recorded using the fine-wire electrodes was less consistent than what was reported for the two surface EMG detection systems in the previous sections (Tables 4-17 to 4-20). The RMS amplitude of the baseline activity was consistent between days in supine when evaluated using the MAD (0.3 to 3.3 µV). The ICCs (Tables 4-17 to 4-20) appear to underestimate the reliability of the fine-wire EMG data. This may be due to the homogeneity of the sample during this task. The
low Spearman’s rho values appear to again be influenced by outliers and the small range of values over which the correlation was computed.

4.5.3.2 BETWEEN DAY RELIABILITY OF EMG DATA RECORDED DURING PFM MVC’S

The ICC and Spearman rho correlation values showed that the data recorded from the PFM using the fine-wire electrodes were inconsistent (ICC’s ranging from 0.02 to 90 and Spearman rho ranging from 0.21 to 0.65) (Tables 4-17 – 4-18). Some of these analyses may, however, be misleading. For example, the EMG data recorded from the left PFM during MVCs performed in supine (ICC = 0.75, Spearman rho = 0.65, p = 0.07) and in standing (ICC = 0.90, Spearman rho = 0.60, p = 0.42) appear to be consistent between days and tasks; however, the normalized MAD values clearly indicate that the data are highly variable (55.8% and 61.7% respectively). Figure 4-8 clearly demonstrates how the Spearman rho correlation coefficient was overestimated due to the small sample size and variability in subject scores (left side of figure). The right side of Figure 4-8 gives an accurate representation of what the raw data looked like when the RMS amplitudes were plotted between days. The MAD and normalized MAD displayed in Tables 4-17 to 4-18 appear to reflect the test-retest reliability more accurately as it takes into account the individual differences between days and not just the differences of the group means between days. These values suggest that the fine wire electrodes did not result in reliable PFM MVC EMG data recorded between days. The results from the fine-wire electrodes must be taken with caution due to the low subject numbers.
4.5.3.3 BETWEEN DAY RELIABILITY DURING COUGHING

Like the baseline and peak amplitudes recorded during the MVC tasks using the fine-wire electrodes, during the coughing tasks there continued to be a high level of inconsistency. In this case, the ICC appears to provide a gross overestimate of the reliability of the data (Tables 4-19 and 4-20). The normalized MAD of the RMS amplitudes between days for the cough data were 66% (range 45.6-82.5%), suggesting high variability. Again though, when the RMS amplitudes from the cough data were normalized to the RMS amplitudes of the MVC, the percent of maximum voluntary activation was consistent with what was reported for the other devices (79.5 - 90.0%) which appears to be quite repeatable despite the low reliability coefficients.

4.5.3.4 SIGNAL TO NOISE RATIO

The SNR is directly related to both the amplitude of the signal and the baseline activity. Since it was found that amplitude measures from the EMG data recorded with the fine-wires were not consistent between days, it is not surprising that the SNR was also not found to be reliable.
Table 4-17: Between day reliability of PFM MVC EMG amplitude data when performed in supine and recorded using fine wire electrodes

<table>
<thead>
<tr>
<th></th>
<th>Day One</th>
<th>Day Two</th>
<th>MAD</th>
<th>nMAD</th>
<th>ICC</th>
<th>Spearman Rho (ρ)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMS Amplitude (µV)</strong></td>
<td>Right</td>
<td>85.0(49.0)</td>
<td>60.2(52.3)</td>
<td>65.8(29.0)</td>
<td>97.1%</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>64.2(64.1)</td>
<td>72.5(75.2)</td>
<td>39.9(46.3)</td>
<td>55.8%</td>
<td>0.75</td>
</tr>
<tr>
<td><strong>Baseline RMS Amplitude (µV)</strong></td>
<td>Right</td>
<td>2.6(1.4)</td>
<td>2.3(0.3)</td>
<td>1.0(0.8)</td>
<td>49.6%</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>2.1(0.9)</td>
<td>2.2(0.3)</td>
<td>0.6(0.6)</td>
<td>33.1%</td>
<td>0.23</td>
</tr>
<tr>
<td><strong>SNR (dB)</strong></td>
<td>Right</td>
<td>23.0(6.2)</td>
<td>25.7(8.8)</td>
<td>8.3(4.8)</td>
<td>55.8%</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>26.2(7.9)</td>
<td>27.2(8.8)</td>
<td>5.2(3.9)</td>
<td>18.6%</td>
<td>0.81</td>
</tr>
</tbody>
</table>

*Denotes that the correlation is significant (p<0.05). Reported values are means with the number in brackets representing standard deviation. Right (Rt) side PFM had n=8, and Left (Lt) side PFM had n=9.

Table 4-18: Between day reliability of PFM MVC EMG amplitude data when recorded in standing and recorded using fine wire electrodes

<table>
<thead>
<tr>
<th></th>
<th>Day One</th>
<th>Day Two</th>
<th>MAD</th>
<th>nMAD</th>
<th>ICC</th>
<th>Spearman Rho (ρ)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMS Amplitude (µV)</strong></td>
<td>Right</td>
<td>54.7(33.7)</td>
<td>60.3(46.2)</td>
<td>53.4(28.8)</td>
<td>95.5%</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>60.2(53.4)</td>
<td>98.1(82.8)</td>
<td>40.9(38.7)</td>
<td>61.7%</td>
<td>0.60</td>
</tr>
<tr>
<td><strong>Baseline RMS Amplitude (µV)</strong></td>
<td>Right</td>
<td>5.4(5.6)</td>
<td>2.5(0.5)</td>
<td>3.3(5.5)</td>
<td>55.9%</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>3.0(0.9)</td>
<td>2.1(0.2)</td>
<td>0.8(0.9)</td>
<td>29.5%</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>SNR (dB)</strong></td>
<td>Right</td>
<td>21.9(6.2)</td>
<td>25.1(8.5)</td>
<td>7.6(4.4)</td>
<td>32.1%</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>23.7(9.5)</td>
<td>30.2(9.3)</td>
<td>6.5(3.9)</td>
<td>26.9%</td>
<td>0.96</td>
</tr>
</tbody>
</table>

*Denotes that the correlation is significant (p<0.05). Reported values are means with the number in brackets representing standard deviation. Right (Rt) side PFM had n=7, and Left (Lt) side PFM had n=4.

Table 4-19: Between day reliability of PFM EMG amplitude data when a coughing task was performed in supine and recorded using fine-wire electrodes

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
<th>MAD</th>
<th>nMAD</th>
<th>ICC</th>
<th>Spearman Rho (ρ)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMS amplitude (µV)</strong></td>
<td>Right</td>
<td>65.4(37.7)</td>
<td>75.3(85.7)</td>
<td>50.9(54.7)</td>
<td>73.5%</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>66.1(61.4)</td>
<td>62.5(55.9)</td>
<td>27.4(29.9)</td>
<td>45.6%</td>
<td>0.85</td>
</tr>
<tr>
<td><strong>%MVE</strong></td>
<td>Right</td>
<td>90.9(7.4)</td>
<td>88.4(6.8)</td>
<td>11.6(7.1)</td>
<td>13.2%</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>79.5(20.1)</td>
<td>83.4(17.2)</td>
<td>17.0(19.7)</td>
<td>24.2%</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Baseline RMS amplitude (µV)</strong></td>
<td>Right</td>
<td>2.4(0.6)</td>
<td>2.2(0.4)</td>
<td>0.4(0.3)</td>
<td>15.9%</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>2.4(0.9)</td>
<td>2.4(0.6)</td>
<td>0.7(0.7)</td>
<td>27.0%</td>
<td>0.60</td>
</tr>
<tr>
<td><strong>SNR (dB)</strong></td>
<td>Right</td>
<td>27.9(4.8)</td>
<td>25.4(10.2)</td>
<td>7.9(5.8)</td>
<td>31.7%</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>25.6(8.8)</td>
<td>26.5(6.5)</td>
<td>5.8(5.6)</td>
<td>22.6%</td>
<td>0.00</td>
</tr>
</tbody>
</table>

*Denotes that the correlation is significant (p<0.05). Reported values are means with the number in brackets representing standard deviation. Right (Rt) and left (Lt) side of the PFM had n=7.
Table 4-20: Between day reliability of PFM EMG amplitude data when a coughing task was performed in standing and recorded using fine-wire electrodes

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
<th>MAD</th>
<th>nMAD</th>
<th>ICC</th>
<th>Spearman Rho (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMS amplitude (µV)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>44.7(37.4)</td>
<td>48.9(40.0)</td>
<td>23.1(22.3)</td>
<td>61.8%</td>
<td>0.76</td>
<td>p = 0.80, p = 0.13</td>
</tr>
<tr>
<td>Left</td>
<td>34.0(33.5)</td>
<td>36.0(50.7)</td>
<td>27.6(27.0)</td>
<td>82.5%</td>
<td>0.72</td>
<td>p = -0.05, p = 0.93</td>
</tr>
<tr>
<td><strong>%MVE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>86.4(11.8)</td>
<td>85.3(7.4)</td>
<td>8.4(5.9)</td>
<td>10.0%</td>
<td>0.55</td>
<td>p = 0.40, p = 0.52</td>
</tr>
<tr>
<td>Left</td>
<td>87.1(13.2)</td>
<td>87.1(6.6)</td>
<td>12.9(9.4)</td>
<td>15.1%</td>
<td>0.00</td>
<td>p = 0.00, p = 0.88</td>
</tr>
<tr>
<td><strong>Baseline RMS amplitude (µV)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>3.3(1.7)</td>
<td>2.5(0.3)</td>
<td>1.3(1.4)</td>
<td>38.7%</td>
<td>0.00</td>
<td>p = -0.30, p = 0.68</td>
</tr>
<tr>
<td>Left</td>
<td>2.4(0.5)</td>
<td>2.3(0.5)</td>
<td>0.3(0.4)</td>
<td>13.1%</td>
<td>0.56</td>
<td>p = 0.71, p = 0.09</td>
</tr>
<tr>
<td><strong>SNR (dB)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>20.6(7.9)</td>
<td>23.4(8.4)</td>
<td>7.1(3.4)</td>
<td>32.8%</td>
<td>0.67</td>
<td>p = 0.00, p = 0.35</td>
</tr>
<tr>
<td>Left</td>
<td>19.7(7.2)</td>
<td>20.6(8.4)</td>
<td>7.1(5.3)</td>
<td>37.7%</td>
<td>0.45</td>
<td>p = -0.02, p = 0.98</td>
</tr>
</tbody>
</table>

*Denotes that the correlation is significant (p≤0.05). Reported values are means with the number in brackets representing standard deviation. Right (Rt) side PFM had n=5, and Left (Lt) side PFM had n=8 (Baseline n = 7 on the left)

4.5.4 COMPARISON AMONG INSTRUMENTS

The between-day reliability was poor for all three devices when the RMS amplitudes were compared on day one and day two (Table 21). Lower normalized mean absolute differences were found in the RMS amplitudes between days using surface electrodes (nMAD = 20.9 to 47.6%) compared to fine-wire electrodes (45.6% to 97.1%). The values obtained for the ICCs and Spearman correlation coefficients were inconsistent between the right and left sides of the PFM, the different tasks, and different devices.

When the RMS amplitudes recorded during the coughing tasks were normalized to each subject's maximum voluntary pelvic floor muscle contraction the nMAD indicates that normalized EMG data are more reliable (surface electrodes nMAD = 7.5 to 14.4%; fine-wire nMAD = 10.0 to 24.2%) than the raw data described above, and like the raw data, between-day reliability is slightly higher using surface electrodes compared to fine-wire. The low values reported for the ICCs and Spearman’s correlation coefficient can be explained by the homogeneous nature of the sample as displayed in Figure 4-7.
Table 21: Between-day Reliability of the RMS amplitude for the three different devices across all tasks

<table>
<thead>
<tr>
<th>Task</th>
<th>Device</th>
<th>Device</th>
<th>MAD (uV)</th>
<th>nMAD</th>
<th>ICC</th>
<th>Spearman’s Rho (ρ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Right</td>
<td>9.3 (10.4)</td>
<td>20.9%</td>
<td>0.79</td>
<td>p = 0.72*, p=0.02</td>
</tr>
<tr>
<td>Supine MVC</td>
<td>Femiscan™</td>
<td>Left</td>
<td>15.6(13.0)</td>
<td>38.6%</td>
<td>0.63</td>
<td>p = 0.48, p=0.16</td>
</tr>
<tr>
<td></td>
<td>Periform™</td>
<td>Right</td>
<td>40.4(44.3)</td>
<td>24.9%</td>
<td>0.89</td>
<td>p = 0.92*, p &lt; 0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Left</td>
<td>37.3(27.4)</td>
<td>31.5%</td>
<td>0.79</td>
<td>p = 0.76*, p = 0.01</td>
</tr>
<tr>
<td></td>
<td>Fine-Wire</td>
<td>Right</td>
<td>65.8(29.0)</td>
<td>97.1%</td>
<td>0.02</td>
<td>p = 0.21, p = 0.62</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Left</td>
<td>39.9(46.3)</td>
<td>55.8%</td>
<td>0.75</td>
<td>p = 0.65, p = 0.07</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right</td>
<td>10.7(11.0)</td>
<td>34.6%</td>
<td>0.49</td>
<td>p = 0.40, p = 0.29</td>
</tr>
<tr>
<td>Supine Cough</td>
<td>Femiscan™</td>
<td>Left</td>
<td>17.0(11.5)</td>
<td>47.6%</td>
<td>0.70</td>
<td>p = 0.45, p = 0.23</td>
</tr>
<tr>
<td></td>
<td>Periform™</td>
<td>Right</td>
<td>44.6(29.9)</td>
<td>35.6%</td>
<td>0.94</td>
<td>p = 0.76*, p = 0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Left</td>
<td>52.5(58.8)</td>
<td>37.3%</td>
<td>0.42</td>
<td>p = -0.01, p = 0.99</td>
</tr>
<tr>
<td></td>
<td>Fine-Wire</td>
<td>Right</td>
<td>50.9(54.7)</td>
<td>73.5%</td>
<td>0.49</td>
<td>p = 0.51, p = 0.24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Left</td>
<td>27.4(29.9)</td>
<td>45.6%</td>
<td>0.85</td>
<td>p = 0.79*, p = 0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right</td>
<td>7.36(6.14)</td>
<td>24.2%</td>
<td>0.67</td>
<td>p = 0.66*, p=0.04</td>
</tr>
<tr>
<td>Standing MVC</td>
<td>Femiscan™</td>
<td>Left</td>
<td>16.0(17.2)</td>
<td>42.8%</td>
<td>0.36</td>
<td>p = 0.22, p=0.56</td>
</tr>
<tr>
<td></td>
<td>Periform™</td>
<td>Right</td>
<td>59.1(49.2)</td>
<td>42.2%</td>
<td>0.54</td>
<td>p = 0.59, p = 0.07</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Left</td>
<td>48.2(52.6)</td>
<td>35.0%</td>
<td>0.58</td>
<td>p = 0.72*, p = 0.03</td>
</tr>
<tr>
<td></td>
<td>Fine-Wire</td>
<td>Right</td>
<td>53.4(28.8)</td>
<td>95.5%</td>
<td>0.00</td>
<td>p = -0.21, p = 0.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Left</td>
<td>40.9(38.7)</td>
<td>61.7%</td>
<td>0.90</td>
<td>p = 0.60, p = 0.42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right</td>
<td>7.94(11.4)</td>
<td>31.6%</td>
<td>0.77</td>
<td>p = 0.55, p = 0.17</td>
</tr>
<tr>
<td>Standing Cough</td>
<td>Femiscan™</td>
<td>Left</td>
<td>7.47(12.8)</td>
<td>27.0%</td>
<td>0.57</td>
<td>p = 0.26, p = 0.54</td>
</tr>
<tr>
<td></td>
<td>Periform™</td>
<td>Right</td>
<td>70.1(77.1)</td>
<td>38.7%</td>
<td>0.68</td>
<td>p = 0.45, p = 0.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Left</td>
<td>47.5(45.1)</td>
<td>26.9%</td>
<td>0.84</td>
<td>p = 0.48, p = 0.16</td>
</tr>
<tr>
<td></td>
<td>Fine-Wire</td>
<td>Right</td>
<td>23.1(22.3)</td>
<td>61.8%</td>
<td>0.75</td>
<td>p = 0.80, p = 0.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Left</td>
<td>27.6(27.0)</td>
<td>82.5%</td>
<td>0.72</td>
<td>p = -0.05, p = 0.93</td>
</tr>
</tbody>
</table>
Table 22: Normalized RMS amplitudes recorded during the coughing tasks

<table>
<thead>
<tr>
<th>Task</th>
<th>Device</th>
<th>Right</th>
<th>Day 1 (%MVE)</th>
<th>Day 2 (%MVE)</th>
<th>MAD (uV)</th>
<th>nMAD</th>
<th>ICC</th>
<th>Spearman’s Rho (ρ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Day 1 (%)</td>
<td>Day 2 (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(MVE)</td>
<td>(MVE)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right</td>
<td>86.4(14.7)</td>
<td>85.3(8.1)</td>
<td>11.2(9.91)</td>
<td>14.4%</td>
<td>0.30</td>
<td>ρ = 0.02, p = 0.98</td>
</tr>
<tr>
<td>Supine Cough</td>
<td>Femiscan™</td>
<td>Right</td>
<td>88.5(7.5)</td>
<td>88.7(5.8)</td>
<td>8.34(5.08)</td>
<td>9.3%</td>
<td>0.00</td>
<td>ρ = -0.10, p = 0.81</td>
</tr>
<tr>
<td></td>
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<td>Left</td>
<td>88.0(9.3)</td>
<td>89.0(6.3)</td>
<td>10.9(8.0)</td>
<td>12.7%</td>
<td>0.00</td>
<td>ρ = 0.50, p = 0.14</td>
</tr>
<tr>
<td></td>
<td>Periform™</td>
<td>Right</td>
<td>90.0(7.6)</td>
<td>90.2(5.7)</td>
<td>6.7(4.3)</td>
<td>7.5%</td>
<td>0.38</td>
<td>ρ = -0.10, p = 0.81</td>
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<td></td>
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<td>90.0(7.6)</td>
<td>90.2(5.7)</td>
<td>6.7(4.3)</td>
<td>7.5%</td>
<td>0.38</td>
<td>ρ = 0.50, p = 0.14</td>
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<tr>
<td></td>
<td>Fine-Wire</td>
<td>Right</td>
<td>90.9(7.4)</td>
<td>88.4(6.8)</td>
<td>11.6(7.1)</td>
<td>13.2%</td>
<td>0.00</td>
<td>ρ = -0.36, p = 0.44</td>
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<td>83.4(17.2)</td>
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<td>24.2%</td>
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<td>87.3(7.5)</td>
<td>86.1(6.8)</td>
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<td>0.16</td>
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<td>Standing Cough</td>
<td>Femiscan™</td>
<td>Right</td>
<td>86.5(9.4)</td>
<td>88.9(6.3)</td>
<td>9.95(8.40)</td>
<td>11.5%</td>
<td>0.00</td>
<td>ρ = -0.04, p = 0.93</td>
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<td></td>
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<td>Left</td>
<td>86.5(9.4)</td>
<td>88.9(6.3)</td>
<td>9.95(8.40)</td>
<td>11.5%</td>
<td>0.00</td>
<td>ρ = -0.04, p = 0.93</td>
</tr>
<tr>
<td></td>
<td>Periform™</td>
<td>Right</td>
<td>90.7(5.8)</td>
<td>85.2(7.3)</td>
<td>7.6(5.9)</td>
<td>8.9%</td>
<td>0.40</td>
<td>ρ = 0.15, p = 0.70</td>
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<td>9.6%</td>
<td>0.00</td>
<td>ρ = 0.01, p = 0.99</td>
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<td>Right</td>
<td>86.4(11.8)</td>
<td>85.3(7.4)</td>
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<td>0.55</td>
<td>ρ = 0.40, p = 0.52</td>
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<td>15.1%</td>
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Chapter 5  DISCUSSION

5.1 SUBJECTS

A convenience sample of 12 healthy women between the ages of 24 and 40 participated in the study. All of the subjects were nulliparous and had no prior history of any type of pelvic floor dysfunction. The results from this study cannot be generalized to women who have had children, women outside of the specified age range, or those who have urinary incontinence.

Ideally, the evaluation of PFM function by the physiotherapist should not have been performed between the two EMG evaluation sessions. For most subjects, this was the first time they had experienced a PFM evaluation of this type, and therefore there could have been a learning effect introduced by the manual feedback provided during the physical exam or by the first test session that may have skewed the between-day reliability. Despite this, in our sample as a whole, there was no main effect of day in the analysis of variance, which suggests that EMG activation amplitudes were not systematically higher on the second day of EMG evaluation, and as such that there was no generalized learning effect. In addition, the PFM evaluation was only performed between the two EMG testing sessions in two of our twelve subjects. Data from one of these subjects was not included in the analysis, as described in Section 3.2. In the other subject, no systematic differences were identified between the EMG data recorded on day one and day two.

5.2 DATA INCLUSION/EXCLUSION

5.2.1 SUBJECTS DATA THAT WERE EXCLUDED

A number of validity and reliability issues were presented in the literature review that pertain to EMG data acquisition, especially with regards to EMG data recorded from the PFM
using surface electrodes. The ability to properly contract the PFM was assessed during the physiotherapy PFM function evaluation. Manual muscle testing (MMT) of the PFM in two subjects was assigned a grade less than three out of five using the modified Oxford scale. One subject was assigned a grade a one out of five (flicker) and the other was assigned a grade a two out of five (weak). The Femiscan™ vaginal probe and fine-wire electrodes failed to detect EMG activity during any tasks in the subject who scored the one out of five. Interestingly EMG activation of the PFM was detected from this subject using the Periform™ vaginal probe during the cough tasks. It is suspected that the Periform™ vaginal probe may have been recording crosstalk from activation of other muscles that increase the IAP,\(^2\) during the cough because of the large monopolar detection surfaces (Figure 2-2), and the position of the probe within the vaginal canal which in a recent study was found to be caudal to the pelvic floor muscles.\(^2\)

### 5.2.2 USING SNR TO VERIFY SIGNAL QUALITY

The PFM support the pelvic viscera, help to regulate IAP,\(^16\) and aid in maintaining continence, most of which occur without conscious effort. Tonic activity of the PFM has been reported\(^4\)\(^8\) in some women and therefore when verifying raw EMG data files it is important to distinguish between extraneous noise and tonic muscle activation. The signal to noise ratio of each EMG data file was computed. When the SNR of the EMG activity recorded during MVC or cough tasks was less than 10dB the signal was excluded from the analysis because it was not clear whether the subject did not perform a PFM contraction or whether the amplitude of the contraction was simply low. In the event that the SNR was between 10 and 12 dB, the data files were visually inspected to verify adequate data quality. Specifically, if a data file was found to have a SNR less than 12dB and the onset of muscle activity was visually indistinguishable from the baseline EMG amplitude, the data file was excluded. This approach was valid given our
sample of young, nulliparous, continent women who, after excluding subjects who on physical exam showed signs of pelvic floor muscle dysfunction, were able to perform an appropriate PFM contraction. This approach might be less valid if patient populations are tested as it is entirely possible that some subjects are not able to generate RMS amplitudes that are large enough to produce a SNR greater than 10dB due to weakness or neurological defects.

5.2.3 DATA FILES FROM SURFACE ELECTRODES THAT WERE EXCLUDED

The EMG data recorded using the Periform™ vaginal probe were least sensitive to motion artifact in comparison to the other devices used in this study, likely because of its shape and size (Figure 2-2). When EMG data files were recorded during the cough tasks using the Femiscan™ vaginal probe, some of the data files were excluded because motion artifact was identified during visual inspection. The Femiscan™ is basically a smooth plastic cylinder that is inserted into the vaginal canal, and it sits upon a base which contains the pre-amplifier electronics for the electrodes embedded on its sides (Figure 2-1). This probe is prone to movement because of the weight of the base and its low friction plastic surface. Subjects donned underwear to help support the probe base and keep the probe in position, however probe position was more difficult to maintain in standing and when the subjects were asked to cough.

5.2.4 QUALITY OF THE EMG DATA RECORDED USING THE FINE-WIRE ELECTRODES

Visual verification of EMG data acquired using fine-wire electrodes revealed that the onset of muscle activation was very distinct. Two different patterns of muscle activation were identified in EMG activity recorded using the fine-wire electrodes at rest. Similar to what was identified in a study by Deindl et al.4,8 phasic patterns of baseline EMG activity were observed in a number of subjects and in others, tonic activation in baseline EMG data recorded were
observed. The pattern observed in each subject was not always consistent between test sessions, suggesting that PFM EMG activity at rest is dependent on the proximity of the wire tips to the active motor unit pool. Even when using precise anatomical landmarks for fine-wire insertion, it is impossible to know that one is recording data from the same motor unit pool on separate testing days.

There were a number of fine wire EMG data files that were excluded from the analysis. When an electrode became dislodged from one side of the PFM during a testing session, the EMG data files for the opposite side of the pelvic floor were excluded in the between side comparisons for that day. Likewise, when between-day reliability was assessed, regardless of the quality of the signal from the “other” day, the data files from both days for that side of the pelvic floor also had to be excluded. Dislodging of wire electrodes was more of a problem in this study than it normally is. This might be due to the fact that the PFM form a thin sheet and therefore provide less opportunity for the hooked wires to become embedded in the muscle tissue. It may also have been due to the fact that the electrode leads were located caudal to the pelvis. The weight of the leads may have been sufficient to pull wires out of position. In addition, with position changes the wires were more likely to become dislodged due to tension being placed on the wires. The instances where wires became dislodged in this study were all related to position changes.

To be sure that the wires were properly inserted into the muscle of interest (PFM), prior to beginning each phase of the testing session, EMG data were recorded across three conditions; resting, a slight PFM contraction and a small cough. If it was suspected that a wire was not positioned properly at the beginning of the test session, new fine-wire electrodes were inserted. If it was suspected that a fine-wire migrated or became dislodged during the testing
session, no new wire was inserted and the remaining tasks for that subject contained no data. In the future, ultrasound imaging to guide fine-wire placement or MR imaging may be valuable to determine the location of the fine-wires within the PFM, however it is anticipated that the difficulty with wires becoming dislodged with position changes will persist.

5.3 EASE OF SUBJECT RECRUITMENT

It is always important to consider subject dignity and comfort when evaluating different measurement devices. Although these factors were not formally addressed in the present study, the themes that were noticed deserve attention.

Investigations of PFM function may be underpowered by low participant numbers related to individuals being uncomfortable with the invasiveness of the data collection procedures, and this study was no different. Key assumptions when using parametric statistics include that the data follow a normal distribution and that data from categorical factors have equal variances, 105 Since a small sample was recruited in this study, tests for normality were performed since these assumptions could not be made.

One of the benefits of using vaginal probes as opposed to fine wire electrodes is that they are relatively comfortable and provide subjects with some modesty. Subjects were able to insert the probes themselves, and then simply have probe position verified by the researcher, which helped modest subjects be more comfortable. It is possible, however, that in response to anxiety the EMG data recorded from the PFM was not the same as that which would be recorded under normal circumstances, e.g. when subjects were not instrumented.

Once in situ, the Periform™ vaginal probe was the most ‘user friendly’ in terms of comfort since the shape and the large diameter of the probe helped to keep the probe in position.
However, the large diameter of the Periform™ probe also caused some concerns. Two women had difficulty trying to insert the Periform™ probe and one potential subject was unable to participate, reporting that the Periform™ vaginal probe simply “did not fit”. It has also been suggested that with the Periform™ the vaginal wall is distended such that the pubrectalis muscle is actually pushed away from the recording surfaces.

The Femiscan™ probe was very easy for subjects to insert. The large base on the Femiscan™ probe sits outside of the vagina and was reported to cause some discomfort during position changes. From the subjects description and anatomical location of the Femiscan™ probe it is thought that the probe was putting pressure on the urethra and compressing it against the pubic symphysis during the PFM MVCs in two of the subjects. Complaints of pain during the MVCs were consistent with decreased RMS amplitudes recorded on the day pain was reported compared to the day when pain was not reported by this subject. Subjects also commented that they felt the probe slipping out of place, particularly during the coughing tasks, and these comments were consistent with motion artifact identified in the recording of the EMG signal. If motion artifact was detected at the time of testing, subjects were invited to repeat the trial and immobilize the Femiscan™ using their free hand.

Subjects reported that they did not feel the fine-wires once they were inserted, but were very cautious when changing positions to avoid dislodging the wires. If the wires remained in place while the vaginal probes were inserted, EMG data were recorded simultaneously from surface and intramuscular electrodes, and these data will be used in further analyses beyond the scope of this thesis. The fine-wires were removed from one subject after the first set of supine and standing tasks were completed when the subject reported feeling light headed and nauseated. This response to the fine-wires was observed on both testing days. Similarly, a
second subject experienced dizziness and nausea after the fine-wires were inserted, but this only occurred in standing on the first day of testing. It is challenging to recruit subjects for studies that involve inserting fine-wire electrodes into their PFM, and caution needs to be taken to watch for autonomic responses to the procedure.

5.4 DIFFERENCES IN EMG ACTIVATION OF THE RIGHT AND LEFT PFM

Each recording device used in the present study to acquire EMG data from the PFM recorded muscle activation bilaterally. Many researchers use devices that can record EMG signals from both sides of the pelvic floor simultaneously. Often only one value is reported to describe the EMG data that were recorded. The right and left sides of the PFM are close anatomically and when working properly they contract as a functional unit. However, they do have different peripheral nerve supplies\(^{106}\) and are susceptible to unilateral damage during vaginal delivery.\(^ {107}\) Differences in PFM activation in women who have pelvic floor muscle dysfunction may not be detected if researchers fail to report the RMS amplitude (or any other EMG parameter) for each side of the pelvic floor.

Reporting only one value for PFM EMG amplitude is similar to a situation where EMG data are simultaneously recorded from the left and right sides of the biceps brachii muscles, using separate bipolar EMG electrodes, and reporting only the mean of the two sides or the side with the larger amplitude, which would preclude the detection of side-to-side differences. If a reliability study were performed using the biceps example, the factors that affect the reliability of the EMG signals recorded from separate biceps muscles would be much the same as the factors affecting the reliability of the EMG signals recorded in the PFM.

Differences in EMG amplitude recorded from the right and left sides of the PFM are expected regardless of which detection system is used, but these differences are not expected
to be systematic. When EMG data were recorded from the PFM using the Femiscan™ vaginal probe a 17-19% difference in activation amplitudes during the PFM MVCs was observed, where left side of the pelvic floor was found to generate higher RMS amplitudes when compared to the right side (p ≤ 0.04) (Table 4-2). This statistical difference was found by comparing the group means using an analysis of variance model, and was surprising. When the same data set were analyzed by calculating the mean absolute difference between the left and right sides, a 13.0-18.2 uV difference was found, representing a side to side difference of 32.8-41.4%. Using the same vaginal probe (Femiscan™) with custom modifications, Madill & McLean87 reported that the RMS amplitudes recorded from each side of the pelvic floor were different, but when cross-correlation analysis were performed they reported that the shape and timing of the signals recorded from each side were no different (r = 0.90 with a 0.0 ms time lag), therefore they chose to use the larger signal in their analysis of the relationship between vaginal pressure generated by a PFM contraction and the PFM activation itself. Side to side differences in activation would have influenced the relationships studied in this work. Similar to the current study, Aukee et al.65 found that EMG data recorded from each side of the pelvic floor was different in all subjects, however when the means between sides of the pelvic floor were compared, statistically there appeared to be no difference. In the recent literature the Periform™ is one of the most commonly used vaginal probes.3,9,16-20 Despite its frequent use, information describing how the EMG signals are acquired is at best, scarce. Recall that the Periform™ has two large stainless steel rectangular detection surfaces on either side; to date it is unknown if the EMG amplitudes reported are the mean of EMG signals recorded from both sides, if a differential recording between the two sides is made, or if the side with the higher amplitude is used in their analyses.3,9,16-20 In the present study, the Periform™ was configured to record monopolar signals from each side of the pelvic floor. The RMS amplitude of the baseline
activity and the SNR were both consistent between the left and right sides. RMS amplitude was 22% higher on the right side of the pelvic floor compared to the left during the PFM MVC in supine (p = 0.01), however, a statistically significant difference was not identified in the other EMG data from the MVC or the cough tasks. Again there was usually a large difference in activation amplitudes between the sides (Table 4-4).

Fine-wire electrodes detect EMG activation from a localized area within the muscle and record from a select number of motor units. When recording EMG data from each side of the pelvic floor using this type of electrode the contribution of motor units to the EMG signals that are recorded at that instant in time are not likely repeatable and therefore are going to be quite different when recording from the left and right sides. The results from this investigation indicate that the difference in the RMS amplitude recorded from each side of the PFM was not statistically significant despite drastic individual differences in activation amplitudes between sides in each individual. When the MAD between sides was computed across all tasks, the difference in EMG amplitude among sides of the PFM ranged from 45 µV to 70 µV, representing an 82 to 101% difference relative to mean signal amplitude.

At rest, the MAD of the RMS amplitude from the right and left sides of the pelvic floor appeared consistent (MAD = 0.5 to 2.2 µV). The normalized MAD represents up to 32.9% of the RMS amplitude of the baseline activity, but considering that the PFM are composed of about 70% type I slow twitch muscles fibers, and have been found to have tonic activity at rest variability between sides would not be unexpected when using fine-wire electrodes that are detecting the activation of completely different motor unit pools.

The large difference observed in signal amplitude recorded from the left and right sides of the PFM using fine-wire electrodes can be explained by the relative position of the detection
surface with respect to the active motor units and to the fact that it is impossible to control the interelectrode spacing between days and sides. It is also impossible to determine where the fine-wire recording surfaces are relative to the motor points of the PFM. The location of the motor point relative to the bipolar electrodes can significantly influence the amplitude of the EMG signal.\textsuperscript{5}

Some subjects had higher EMG amplitudes on the left side and others had higher EMG amplitudes on the right side, thus detecting a true side to side difference in activation amplitudes is nearly impossible using statistical measures that compare group means. There did not appear to be any consistency between tasks, electrodes, or days that would suggest the difference was a systematic one. Perhaps a more useful measure would be to perform a Kappa analysis to investigate the agreement from day to day and between recording instruments to determine if, on a given subject one side produces consistently higher activation amplitudes than the other. This would allow us to determine if the side to side differences are more likely due to differences between the recording systems or due to true differences between sides in a given individual. This analysis will be performed in a future study but an assessment of this issue relative to the current study is provided below.

A key question related to the results of the current study is whether or not the differences in EMG amplitude between sides and the inconsistency in the repeatability of EMG amplitudes between trials and days was due to a true difference in PFM activation or is the poor reliability associated with the subjects response to the device or the device itself? When the amplitude values of the EMG data were inspected across individuals there was no consistent trend within individuals to have higher EMG activation amplitudes on one side versus the other. In fact, there were many cases where the EMG data recorded in supine produced higher
amplitudes on the right side of the PFM but that once the subject stood-up to perform the same task in standing, the left side of the PFM generated higher EMG amplitudes than the right side. These differences were also noted across test sessions.

The distance between the detection surface and the muscle fibers can affect the amplitude of the EMG signal. It is difficult to determine the distance between the PFM and the recording electrodes embedded on the rigid frame of the Femiscan™ and Periform™ vaginal probes. In addition, it is impossible to standardize electrode placement between days. The number and location of motor points has not been identified in the anterior portion of the PFM as yet, but it is suspected that the PFM have multiple motor points on each side. When using a bipolar configuration, the position of the motor point can change the amplitude of the signal if the motor point is not centered with respect the electrode pairs. The location of the motor point is not as big of an issue when using a monopolar configuration such as the Periform™.

It is well known that when recording EMG data from skeletal muscles such as the forearm extensors, adhesive is used to minimize electrode movement during the testing. As the PFM contract they are thought to contract concentrically in a cranio-ventral direction. It is not possible to avoid movement of the probes relative to the muscles as adhesives are not used when recording EMG from the PFM. It is not surprising then that motion artefact was visible on the surface EMG data files, particularly with the Femiscan™. The initial position and migratory motion of the electrodes relative to the underlying muscle might also have resulted in amplitude differences between sides of the PFM and between trials and days. In our experience with the Femiscan™ probe, it appears that at times the probe can tilt to one side or the other – this could lead to higher EMG amplitudes being recorded on one side of the PFM where the muscle tissue is pressed more closely to the recording electrodes.
Even if it were certain that the position of the recording electrodes relative to the PFM remained consistent, the PFM still have internal properties that can lead to asymmetrical EMG activation between sides. Anatomical variations, motor recruitment patterns, and damage to the neuromuscular structure can affect signal amplitude properties. Functionally, the PFM may not contract symmetrically. The perineal body in some women has been observed to deviate either to the left or to the right side during a PFM contraction suggesting that muscle activation between left and right sides of the PFM is asymmetrical in at least some women. Asymmetrical activation of the right and left sides of the PFM was reported when EMG activity was recorded from both sides of the PFM using fine-wire electrodes in a group of urinary incontinent women, however with no knowledge of the expected side to side differences in healthy continent women, these results may not be supported when the results of the current study are taken in to account. Bernstein reported that the left levator ani muscle was 2.5% thicker compared to the right levator ani muscle (p = 0.004) at rest and 3.5% thicker (p < 0.001) compared to the right during a PFM contraction in a sample of 67 healthy women when examined using perineal ultrasonography. The thickness of a muscle or its cross sectional area is proportional to the number of muscle fibers in that muscle. Muscles with a large cross sectional area can generate higher forces and have higher EMG amplitudes. There is evidence that the amplitude of EMG signals recorded from the PFM during PFM contractions are significantly correlated to the thickness of the distal portion of the pubococcygeal muscle (r = 0.49 in the right and r = 0.53 in the left). The relationship is, however, quite weak and the authors did not state the associate p-values.

5.5 BETWEEN TRIAL RELIABILITY

Overall the between trial reliability ranged from good to excellent for each device (ICC 0.58 – 0.98, CV = 8.5 - 32.5%). With the small sample of subjects participating in the study, the
influence of one or two subjects that performed inconsistently on one day had a large impact on the reliability coefficients calculated. These inconsistencies may be attributed to factors associated with the devices themselves or due to personal factors such as physiology, motivation and ability to perform the task properly on repeated efforts.

When between trial reliability was assessed using a different vaginal probe (stainless steel electrodes were embedded circumferentially on its surface) to record EMG data from the muscles of the pelvic floor, the ICCs reported by Thorp et al.\textsuperscript{93} were somewhat consistent (ICC = 0.90-0.96) with those reported in the current study, when between trial reliability was assessed using the Periform\textsuperscript{™} vaginal probe in a similar task the ICC\textsubscript{(3,1)} = 0.87 – 0.96. What was interesting was that, when the CVs were recorded from the PFM MVC data presented by Thorp et al.\textsuperscript{93} the variability between trials was greater (CV = 46.9%) than what was found in the current study (CV < 17.0%). The details regarding test position and number of repetitions were unclear in the study by Thorp et al.\textsuperscript{93} and when different probe designs with different detection surfaces are used it is difficult to draw conclusions across studies. The circumferential probe shorts the electrical activity between sides of the pelvic floor muscles and as such records the highest activity seen from any point along the circumference of the probe. In addition, such large electrodes minimize the influence of differences in electrode location relative to the motor point, but are more susceptible to crosstalk. As such the activity recorded by the circumferential electrodes would have been expected to be less valid but more reliable.

Using a prototype of the Femiscan\textsuperscript{™} vaginal probe, Aukee et al.\textsuperscript{88} reported high between trial reliability when EMG amplitudes were compared between the second and third trial of PFM MVC in supine (Spearman’s rho = 0.92, p< 0.001). Between trial reliability measured for the
same task in the current study using the same device was also good (ICC(3,1)= 0.80 (right PFM) and ICC(3,1)= 0.86 (left PFM)).

Deindl et al. used fine-wire electrodes to record EMG data from the PFM during a number of tasks in supine and standing concluded that the “reproducibility of individual EMG patterns in both supine and the erect position was excellent for all our patients”. There were no quantitative measures to substantiate the statement. Deindl and co-workers later commented that they did not pay attention to the absolute values of the amplitudes of the EMG signals because of the amplitudes’ dependency on position of the electrodes relative to the muscle fiber orientation and non-standardized inter-electrode distance. In the current study, between trial reliability was determined using the RMS amplitudes from the different tasks, and the results indicated high variability between trials in some instances (CV ranging from 9.8% to 32.5%), despite the high ICC values (mean ICC across tasks = 0.91, median ICC across tasks = 0.95) indicating excellent reliability. It is important to remember that 40% of the data recorded using fine-wire electrodes were not included in the between trial analysis, therefore the sample sizes used to determine between trial reliability were small (between 4 and 8 subjects).

Overall, the between-trial reliability when EMG data are recorded from the PFM was highly variable, at times being good and at others being quite poor relative to the surface electrodes.

The between trial reliability of different devices that record EMG activity from the PFM in different positions and during tasks such as coughing has not previously been established. This is the first study to investigate the between trial reliability of PFM EMG activation during coughing and in the standing position, therefore there is no data to compare the current results to.
Between trial reliability during coughing was found to be good across instruments (Table 4-8). On day 1, the ICC value computed on the right side of the pelvic floor during coughing in supine indicated that between trial reliability was fairly poor (ICC = 0.61) for that task. Likewise, when fine-wire electrodes were used to record EMG activity during coughing in standing, the right side of the PFM appeared to have fairly poor reliability (ICC(3,1) < 0.61). In both cases, one subject had very poor consistency between trials on the right side of the PFM decreasing the ICC values and increasing the CV. In both cases, the inconsistencies were observed only on the right side of the PFM, and the left side was consistent. This suggests that perhaps the problem with reliability was due to subject inconsistency and not the device. Interestingly the Periform™ did not detect this difference. The probe, however, may also be less sensitive to true differences in activation since the monopolar signals are more likely to be contaminated with crosstalk, and large amounts of crosstalk would mask differences in PFM performance.

5.6 BETWEEN DAY RELIABILITY

The between day reliability was inconsistent between detection systems and between tasks. The traditional methods for assessing reliability (correlation coefficients and ICC’s) appeared at times to overestimate and at other times to underestimate the between day reliability of the three instruments used in this study.

Like other skeletal muscles, during a PFM contraction, the amplitude of the EMG signal that is recorded from the PFM is partly dependent on the number of motor units that are recruited during the contraction and the depth of the muscle fibers that are active. These two examples are internal properties of the muscle that can influence test-retest reliability of amplitude characteristics recorded when using surface and wire electrodes. Not only are the
internal properties of muscles important to consider when explaining the results from test-retest reliability studies, but external properties must be considered as well.

The distance between the recording electrode and where the electromyographic signal is originating in the muscle as well as the orientation of the recording electrode to the muscle fiber direction can also influence the amplitude characteristics. The external properties can be controlled for with careful placement of the detection surface on different testing days. Ng et al.\textsuperscript{53} and others have used anatomical landmarks and cadavers to improve electrode positioning on the abdominal muscles to maximize the reliability of the EMG acquisition, however subtle differences in position, orientation and even tissue hydration can affect the repeatability of the acquired signals.\textsuperscript{5}

Making generalized statements about test-retest reliability of EMG activity recorded from the PFM considering current evidence is difficult due to three main factors: a) the test-retest reliability studies completed to-date that use surface electrodes embedded on vaginal probes use devices that are different sizes and that are configured differently, b) details regarding the type of contraction are inconsistent between studies, c) different reliability coefficients are reported and d) women may not perform PFM contractions reliably to begin with.\textsuperscript{94} The evidence suggests that within-day reliability coefficients appear more promising than between-day, which is consistent with the results from other skeletal muscles.

Test-retest reliability has been found to be very good when using surface electrodes to record electromyograms from skeletal muscles (ICC ranges from 0.60 to 0.90).\textsuperscript{49,52,54,55} Yang & Winter\textsuperscript{56} and Kollmitzer et al.\textsuperscript{57} both reported that test-retest reliability could be improved at contraction intensities that were less than 50% MVC. The between-day reliability of EMG activation from the lower leg muscles during gait using surface electrodes simultaneously with
fine-wire electrodes was variable. Between-day reliability coefficients that are reported appear higher and more consistent (e.g. lower range of reliability coefficients presented – all above 0.60) than those reported for other skeletal muscles (see section 2.4 for more detail). This is very interesting considering the limitations presented with respect to recording EMG from the PFM.

Thompson et al.\(^3\) reported that the test-retest reliability of EMG amplitude recorded using the Periform™ probe was excellent (ICC = 0.98, Standard error of the measurement (SEM) of 0.06). This result does suggest very high repeatability and that only a small change in EMG amplitude would be expected on repeat testing. Unfortunately this is one of the cases where the author failed to provide details on how the signals were acquired when using this type of probe. One must also remember that 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 appear to produce more reliable results. For this reason, ICCs should not be used in isolation as measures of repeatability. The SEM can similarly provide a biased estimate of the reliability of the data as this measure is also based on error variance. The results from the current study indicate that the between day reliability ranged from ICC = 0.54 to 0.89 when EMG amplitude during PFM MVCs were recorded using the Periform™. The MAD between days during PFM MVC ranged from MAD = 37.2 - 59.1μV which was equivalent to 24.9 to 42.2% of the amplitude of the signal, therefore it may be difficult to find a statistically significant difference in EMG amplitude resulting from an intervention or when comparing continent women to those with pelvic floor dysfunction using the Perifom™ in a similar manner to how it was used in the present study. SEM measurements were not included in the current analysis due to the low subject numbers in this study.
The poor test-retest reliability that was identified when using fine-wire electrodes to record from the PFM is not surprising. Both internal properties of the PFM (fiber diameter, recruitment of motor units, fiber type distribution, and location/number of motor points) and external factors (detection surface location within the muscle, interelectrode distance, possible electrode migration, anxiety associated with inserting fine-wires) can all influence the EMG signal amplitude. The EMG data that were collected using fine-wires appear useful in determining more accurate estimates of timing of muscle activation. Although beyond the scope of this thesis, the data will later be analyzed to determine the reliability of muscle activation onset timing using the three different instruments.

Low ICC values can be attributed to low between-subject variance. When the range of values for the variables of interest is small, a smaller proportion of the variance will be attributed to error, the denominator in the ICC equation, which can falsely lower the computed ICC value. This was most apparent in the results reported for the normalized cough amplitude (%MVE) where the data appeared to be highly repeatable, but the ICC values were low. Likewise, correlation coefficients can also fail to detect a significant relationship between values recorded on separate testing sessions when the variability within the group is small. Again in the case of the normalized cough data the small range of values (79 to 90%) results in a lower correlation coefficient than would be expected. Another major limitation of using correlation coefficients to assess reliability is demonstrated in the current results—correlation coefficients fail to identify the amount of agreement between variables from day to day and only identify the association between the variables.

One last factor that might influence the reliability and validity of PFM EMG amplitudes measured using vaginal probes is the potential influence of feedback provided by the vaginal
probes themselves on the contractility of the PFM. The diameter of different devices has been found to change the amount of force that can be generated by the PFM.\textsuperscript{110} The Periform™ is larger in diameter but shaped differently than the Femiscan™. The Femiscan™ and Periform™ vaginal probes both likely provided the subjects with feedback during the PFM MVC task. The subjects reported having greater awareness of the presence of the Femiscan™ probe in their vaginal canal compared to the Periform™. When the MVC’s were performed with just the fine-wire electrodes in situ the subjects had no pressure biofeedback and might have performed PFM contractions less consistently. Much of the surface PFM EMG data recorded in this study were recorded while the fine wires remained in situ. A future analysis will compare the EMG data acquired using the fine-wire across the three conditions (fine-wire only, fine-wire with Femiscan™, and fine-wire with the Periform™) during PFM MVC’s to look for changes in wire EMG amplitude and onset repeatability when different pressure biofeedback is provided by using the different intravaginal probes.

The position of the electrode is very difficult to standardize when recording from the pelvic floor muscles. Even between tasks, researchers need to consider the implications for EMG amplitude values when small deviations in probe position occur. Skin resistance, subcutaneous adipose tissue, motor unit distribution and many other factors contribute to variability in the signal amplitude when comparing between subjects or in test re-test conditions.\textsuperscript{51} The use of a normalized signal can help control for these differences, therefore, the amplitude of the cough data were expressed as a percent of their maximum voluntary activation (%MVE) that was recorded during the PFM MVC trials on that day. When the values were examined for the normalized data, the %MVE was found to be very consistent across tasks and days. However, due to the lack of variability between subjects and within subjects, the reliability coefficients significant underestimated the repeatability of this measure.
The generation of the maximum voluntary contraction is dependent upon environmental conditions, subject motivation, and factors related to fatigue. Subjects were given two tasks to perform in supine and standing; a PFM maximum voluntary contraction and a maximum effort single barrel cough. The cough was included in the analysis to assess the reflex activation of the PFM, whereas the PFM MVC was used to assess the voluntary activation of the PFM. A certain amount of variability is expected from the subjects' willingness and ability to perform tasks repetitively.

At some points throughout the testing, subjects complained of discomfort from some of the instrumentation which may have negatively affected between trial and between day reliability. Subjects were very honest about effort levels and the sensations that they were experiencing. In many of the tasks where the between-day reliability is influenced negatively by a single subject with outlying data, it was found that upon reviewing the subject’s file, they had complained of pain, discomfort, fatigue, or that they were having difficulty with a task on that day. This was noticed specifically in two subjects that had significantly lower RMS amplitudes on day two compared to day one when performing PFM MVCs after reporting experiencing pain during the contraction when using the Femiscan™ vaginal probe. There were also reports of fear of discomfort when contracting the PFM maximally when the fine-wires were inserted and when the Femiscan™ vaginal probe was used to record EMG. It is therefore difficult to separate out true differences in performance from differences in the performance of the recording instruments.

Another concern that was not addressed in the present study is the potential effect of hormone fluctuations throughout the menstrual cycle on EMG signal amplitudes that are detected using surface electrodes. Throughout the menstrual cycle changes in hormone levels
change the consistency and amount of moisture that is in the vaginal canal. There were no efforts to document which part of the cycle each subject was in at the time of testing.

The use of EMG activation amplitude may not be suitable for detecting the neuromuscular function of the PFM. This study has highlighted many reliability and validity issues related to this approach.

5.7 CONCLUSIONS AND RECOMMENDATIONS:

Based on this study, a number of recommendations can be made regarding EMG data acquisition from pelvic floor muscles.

In general, all three devices produced good to excellent reliability between trials, but not very good reliability between days. This is consistent with most EMG recordings, which is why reference contractions (often MVCs) are used to normalize the data when comparing EMG amplitudes between subjects and days. The high amount of variability in the EMG amplitude recorded during MVCs in the present study is worrisome when such a contraction might be used for normalization. Despite this, however, the normalized PFM EMG amplitudes found during the coughing tasks suggest that this is still an appropriate approach to use when comparisons between patient and control groups or before and after interventions are tested.

Further, based on the within-day reliability results, the use of EMG data recorded from intravaginal probes can be used to study PFM activity when different contractions or activities are performed in a given position.

Finally, the results of this study suggest that PFM EMG data should be recorded and reported separately from each side of the PFM. That said, further studies should compare the presence of side to side differences in PFM activity to muscle girth and contractility measured
using other methods such as ultrasound or magnetic resonance imaging. The high variability between sides suggests that it will be very difficult to use measures of differences in PFM activation between sides to study PFM dysfunction related to denervation injury.

5.7.1 RECOMMENDATIONS REGARDING THE SPECIFIC DEVICES STUDIED ARE AS FOLLOWS:

i. When using the Femiscan™ vaginal probe, the evaluator should always verify the position of the probe and be sure that the wire that connects the probe to the pre-amplifier is not causing the probe to tilt to one side inside the vaginal lumen. The probe base should be well supported (perhaps held in situ) when performing tasks in standing or tasks that involve changes in IAP that may cause the probe to move. This probe is not ideal for the recording of data in standing or recording data from tasks such as coughing or straining that may result in probe movement.

ii. Although not specifically studied in this thesis, the biggest issue with the Periform™ vaginal probe appears to be its’ susceptibility to recording crosstalk due to its large recording surfaces. It is the only device to have picked up ECG signal at rest, and picked up EMG activity in a subject in which it is unlikely that the PFMs were the source of the signal. Another concern with the use of the Periform™ probe in research is that many authors do not state how their data are acquired. It is suspected that they are using the probe in a differential mode such that differences in activity from the right and left sides of the PFM are being recorded, which is highly inappropriate. Alternatively researchers might be taking the average of peak signal acquired from both surfaces, which, based on the results of the current study, is also inappropriate.

iii. Fine-wire electrodes are difficult to use in the PFM when subjects are active or are required to change positions during the experimental protocol. These electrodes appear to have more value when used to determine muscle onset times as opposed to signal amplitude.
This may be useful for a number of purposes. First, there has been considerable evidence to suggest that the PFM work in synergy with the deep abdominal muscles. Fine-wires may be helpful in detecting more precise onset times when evaluating these relationships and determining if and how the timing of muscle onset may be altered in women with stress urinary incontinence, low back pain, and/or in those with respiratory problems as has been suggested in the literature.\textsuperscript{16-19} Secondly, the use of fine-wire electrodes may reduce the amount of crosstalk contamination recorded from the PFM and may be useful to study the validity of different intravaginal probes with different electrode configurations. The fine wires, although useful in that they are less susceptible to crosstalk, may be of limited value in detecting subtle side to side differences in the PFM.


68. Constantinou CE, Hvistendahl G, Ryhammer A, Nagel LL and Djurhuus JC: Determining the displacement of the pelvic floor and pelvic organs during voluntary contractions using magnetic resonance imaging in younger and older women. BJU Int. 90: 408-14, 2002.


7.1 ETHICS APPROVAL

QUEEN'S UNIVERSITY HEALTH SCIENCES AND AFFILIATED TEACHING HOSPITALS
ANNUAL RENEWAL
Queen's University, in accordance with the “Tri-Council Policy Statement, 1998” prepared by the Medical Research Council,
Natural Sciences and Engineering Research Council of Canada and Social Sciences and Humanities Research Council of
Canada requires that research projects involving human subjects be reviewed annually to determine their acceptability on
ethical grounds.

A Research Ethics Board composed of:

Dr. A.F. Clark	Emeritus Professor, Department of Biochemistry, Faculty of Health Sciences, Queen’s
University (Chair)
Dr. S. Burke	Emeritus Professor, School of Nursing, Queen’s University
Rev. T. Delise	Community Member
Dr. M. Evans	Community Member
Mr. C. Kenny	Community Member
Ms. T.C. Knott	Research & Evaluation, Southeastern Regional Geriatric Program,
Providence Continuing Care Centre – St. Mary’s of the Lake Hospital Site
Dr. J. Low	Emeritus Professor, Department of Obstetrics and Gynaecology,
Queen’s University and Kingston General Hospital
Dr. W. Racz	Emeritus Professor, Department of Pharmacology & Toxicology, Queen’s University
Dr. H. Richardson	Assistant Professor, Department of Community Health & Epidemiology
Project Coordinator, NCIC CTG, Queen’s University
Dr. B. Sinchison	Assistant Professor, Department of Anaesthesiology, Queen’s University
Dr. A.N. Singh	WHO Professor in Psychosomatic Medicine and Psychopharmacology
Professor of Psychiatry and Pharmacology
Chair and Head, Division of Psychopharmacology, Queen’s University
Director & Chief of Psychiatry, Academic Unit, Quinte Health Care,
Belleville General Hospital
Dr. E. Tsai	Assistant Professor, Department of Paediatrics and Office of Bioethics, Queen’s University
Ms. K. Weissbaum	LL.B. and Adjunct Instructor, Department of Family Medicine (Bioethics)

has reviewed the request for renewal of Research Ethics Board approval for the project “Determining quality and reliability of
EMG signal recorded from the pelvic floor muscles (PPM) using fine wire electrodes, monopolar and bipolar electrodes on two
different vaginal probes” as proposed by Dr. Linda McLeen, C. Brown and S. Modil of the School of Rehabilitation Therapy, at
Queen’s University. The approval is renewed for one year, effective August 2, 2007. If there are any further amendments or changes
to the protocol affecting the subjects in this study, it is the responsibility of the principal investigator to notify the Research Ethics
Board. Any unexpected serious adverse event occurring locally must be reported within 2 working days or earlier if required by the
study sponsor. All other adverse events must be reported within 15 days after becoming aware of the information.

Chair, Research Ethics Board

May 18, 2007

ORIGINAL TO INVESTIGATOR - COPY TO DEPARTMENT HEAD - COPY TO HOSPITAL(S) - FILE COPY
Renewal [X] Renewal 2 [ ] Extension [ ]
REB# REH-315-06

- 118 -
7.2 CONSENT FORM

TITLE OF PROJECT:

Determining quality and reliability of EMG signal recorded from the PFM using fine wire electrodes, monopolar and bipolar electrodes mounted on two different vaginal probes

BACKGROUND INFORMATION

You have been invited to participate in a research study directed by Dr. Linda McLean to evaluate the quality and reliability of the electrical activity recorded from the pelvic floor muscles (PFM) from three different measurement tools. Dr. McLean or her research assistant will read through this consent form with you and describe procedures in detail and answer any questions that you may have.

The aim of the study:

The aim of this study is to determine which of the measurement tools listed above will collect the highest quality of electromyographic (EMG) data from the PFM with the highest level of reliability. You will be asked to participate in this study if you are female between the ages of 19 and 40, are nulliparous, have no signs or symptoms of urinary incontinence, and have no prior/current neurological conditions. You will be excluded from participating if you have had a history of gynecological/obstetric surgery or are taking medications that the investigator will ask you about (diuretics, tricyclic antidepressant or alpha adrenergic agonists).

Description of visits, dosage, tests to be performed as part of the study:

If you agree to participate in this study you will be asked to attend two sessions in the motor performance laboratory, one week apart. On the first visit, an experienced physiotherapist will
obtain a brief history and then perform a pelvic floor evaluation to identify any signs of uterine prolapse and to assess your ability to contract the pelvic floor muscles. If you are suitable for the study, the first data recording session will immediately follow the exam and the second one will be scheduled for 1 week later.

Both data recording sessions will be similar. You will be asked to void yourself of urine immediately prior to data collection. You will be located in a private room for all of the procedures. First you will be instructed on how to use the peak flow meter to record the strength of your cough.

The fine wire electrodes will be inserted into your left and right pelvic floor muscles by a physiotherapist trained to insert intramuscular electrodes. A topical anesthetic cream will be applied to the area where the wires will be inserted to reduce discomfort. The leads will be adhered to your inner thigh using tape. You will feel a sensation similar to getting an intramuscular injection while the wires are being positioned, once the wires are in place, you should not feel any discomfort. If at any time during this portion of the study you feel uncomfortable or are experiencing any discomfort, testing may be stopped upon your request.

For the tests involving the use of the vaginal probes, you will be given verbal instructions by the investigator on how to insert the probe into your vagina, and will be left alone to situate the probe appropriately. Inserting the probe is not substantially different from inserting a tampon when you are menstruating. Once the probe is situated, you will indicate to the investigator that you are ready for her to return. If you feel any discomfort with the probe inserted, please inform the investigators. You may remove the probe and abandon the session at any time without any negative consequences.
The data recording sessions will involve the performance of the following tasks in two different positions: lying on your back and standing up, with each measurement tool (bipolar vaginal probe, monopolar vaginal probe, and fine wire electrodes).

1. You will be asked to assume a comfortable and relaxed position and data will be recorded as you do so.
2. You will be asked to perform three repetitions of the strongest contraction that you can using your pelvic floor muscles. You will hold each contraction for 4 seconds.
3. You will be asked to perform three repetitions of a maximal effort cough during a 4 second recording period. The strength of your cough will be documented from the reading on the peak flow meter.
4. You will be asked to perform three repetitions of a maximal effort Valsalva maneuver during a 4 second recording period.
5. If the intramuscular electrodes remain in place after the probe is inserted, in the supine position, you will be asked to perform some resisted hip movements (squeeze legs together, rotate legs, lift buttocks off of the table, and perform a posterior pelvic floor muscle contraction).

**Alternative Therapies**

You will not receive any form of treatment through participating in this study. The researchers will educate you on how to do a proper pelvic floor muscle contraction, which is important for ongoing health of your pelvic floor muscles.

**Risks/Side-Effects**

There are no known negative side effects reported to occur with pelvic floor muscle contractions nor with the vaginal probe devices used in this study. Each probe is made for single subject use. The experimental procedure poses minimal risk to participants. The EMG amplifiers are isolated from ground and carry a risk of electric shock that is lower than that incurred when turning on a desk lamp. The use of needles carry some risk of infection. Standard precautions will be used to minimize this risk. In particular the needles used to insert the wires are single-use and pre-sterilized. The skin surface will be cleaned with rubbing alcohol prior to insertion of the needles.
The needles will be disposed of using appropriate techniques. Should either of the probes or fine wire electrodes cause any unusual feelings or symptoms, please report these immediately to the investigator.

**Benefits**

While you may not benefit directly from this study, results from this study may improve the quality of the recording devices used to measure pelvic floor muscle activity. This will then contribute to our ability to improve the understanding of how the muscles of the pelvic floor function under normal circumstances and how they are affected in women with stress urinary incontinence. This information may benefit future patients by allowing us to design optimal treatment programs. Through participating in this study, you will learn exercises that have been proven to be effective at reducing the frequency and severity of urinary incontinence.

**Exclusions:**

You will not be considered for this study if you are taking diuretics, tricyclic antidepressants or alpha adrenergic agonist medications, if you have had any pregnancies or are currently pregnant, have a history of urinary incontinence symptoms, uterine prolapse, prior gynecological surgeries, or if you have any neurological conditions.

**Confidentiality:**

All information obtained during the course of this study is strictly confidential and your anonymity will be protected at all times. You will be identified by a subject number only, not your name. Data will be stored in locked files and will be available only to the investigators. Only the principle investigator will have access to your name. Any use of your data for teaching purposes, publications or reports will not reveal you identity.
Voluntary nature of study/Freedom to withdraw or participate:

Your participation in this study is voluntary. You may withdraw from this study at any time and your withdrawal will not affect your future medical care with any physician, physiotherapist or nurse at any hospital or clinic.

Withdrawal of subject by principle investigator:

The investigators may decide to withdraw you from this study if you are unable to learn the pelvic floor muscle contractions, or if the screening examination reveals any degree of uterine or other prolapse.

Liability:

In the event that you are injured as a result of taking part in this study medical care will be provided to you until resolution of the medical problem. By signing this consent form, you do not waive your legal rights nor release the investigator(s) and sponsor from their legal and professional responsibilities.

Payment: No payment is offered for participation of this study.

SUBJECT STATEMENT AND SIGNATURE SECTION:

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 chose 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

Dr. Linda McLean (Principle Investigator)  at  (613) 533-6101

or

Dr. Elsie Culham (Department Head)  at  (613) 533-6727

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

Dr. Albert Clark, Chair, Research Ethics Board  at  (613) 533-6081

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

_______________________________________  ______________________
Volunteer Signature  Date

_______________________________________  ______________________
Witness Signature  Date

STATEMENT OF INVESTIGATOR:

I, or one of my colleagues, have carefully explained to the subject the nature of the above research study. I clarify that, to the best of my knowledge, the subject understands clearly the nature of the study and demands, benefits, and risks involved to participate in this study.

_______________________________________  ______________________
Principle Investigator  Date
7.3 DEMOGRAPHIC, MEDICAL HISTORY AND UI QUESTIONNAIRE

Subject Questionnaire

PFM Reliability Study: Subject Questionnaire

<table>
<thead>
<tr>
<th>Subject Code:</th>
<th>Date:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight:</td>
<td></td>
</tr>
<tr>
<td>Height:</td>
<td></td>
</tr>
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</table>

Screening Questions:

1. Describe any previous gynecological/obstetric surgeries you have had:

2. Have you ever had any previous neurological conditions? YES (if yes, describe)  NO

3. Have you ever experienced chronic or acute low back pain, sacro-iliac joint dysfunction, or joint/muscle problems with your hips? YES  NO

4. Describe any previous musculoskeletal injuries that you have had:

5. Have you ever participated in pilates? Yoga? Or any training that specifically targeted your pelvic floor muscles or deep abdominal muscles? YES  NO (please indicate which and for how long)
**Incontinence Questionnaire:** (please fill out the following chart)

<table>
<thead>
<tr>
<th>Do you leak urine (even small drops), wet yourself, or wet your pads or undergarments</th>
<th>Never Score 0</th>
<th>Less than 1/month Score 1</th>
<th>More than 1/month Score 2</th>
<th>Less than 1/week Score 3</th>
<th>More than 1/week Score 4</th>
<th>Daily Score 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. When you cough or sneeze?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. When you bend down or lift something up?</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3. When you walk, jog, or exercise?</td>
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<tr>
<td>4. When you change position?</td>
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<tr>
<td>5. Do you have to rush to the bathroom because you get a sudden, strong need to urinate?</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>6. Do you get such a strong and uncomfortable need to urinate that you leak urine (even small drops) or wet yourself before you reach the toilet?</td>
<td></td>
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<tr>
<td>7. While you are undressing to use the toilet?</td>
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</tbody>
</table>
### PFM Reliability Study: Physical Exam

<table>
<thead>
<tr>
<th>Subject Code:</th>
<th>Date:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consent Obtained:</td>
<td>(Initial)</td>
</tr>
<tr>
<td>Evidence of Prolapse:</td>
<td>(Y/N)</td>
</tr>
</tbody>
</table>

#### Note direction pelvic floor moves with (observation)

<table>
<thead>
<tr>
<th>Cough</th>
<th>Valsalva</th>
</tr>
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<tbody>
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<td></td>
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</table>

#### Global MMT – (modified Oxford)

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<th>RT</th>
<th>LT</th>
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### PERFECT

#### Performance: Measure of Strength

<table>
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<tr>
<th>RT</th>
<th>LT</th>
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<tbody>
<tr>
<td>A absent</td>
<td></td>
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<tr>
<td>W weak</td>
<td></td>
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<tr>
<td>N normal</td>
<td></td>
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<tr>
<td>S strong</td>
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</table>

#### Co-ordination

<table>
<thead>
<tr>
<th>RT</th>
<th>LT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sluggish</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td></td>
</tr>
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</table>

#### Endurance: Time (s) that contraction is held before a drop of strength of > 50% (up to 10s)

*if not symmetrical, use stronger side for the next two tests

#### Repetitions - Number of times that the long contraction is repeated with 4 seconds rest between each contraction. (Up to 10)

#### Fast contractions: Number of fast strong 1 second contractions. (Up to 10)

#### Elevation: Elevation of pelvic floor and bladder neck with PFM contraction (visceral mobility)

#### Co-contraction of the transversus abdominis with PFM contraction: (YES/NO)

#### Timing of involuntary contraction: with cough

### NOTES
7.5  PERFECT SCHEME

P: Performance

E: Endurance

R: Repetitions

F: Fast Contractions

E: Elevation of bladder neck and pelvic floor with a PFM contraction

C: Co-contraction with transversus abdominis

T: Timing of involuntary contraction of PFM during a cough

The evaluator graded the strength (Absent, Weak, Normal, or Strong) and co-ordination (Sluggish or Normal) of the right and left sides of the PFM during an MVC to begin the test (Performance). The subjects ability to maintain a strong contraction (>50% of the MVC) for ten seconds was then assessed bilaterally (Endurance). If there were no asymmetries detected between left and right sides in the endurance task, the next two tasks were tested only on the right side. However, if the subject demonstrated asymmetry in PFM endurance, the stronger side was used for the next two tasks, as indicated by the developer of the assessment tool. Repetitions were tested as the number of times that the subject could generate and hold a maximal PFM contraction for ten seconds with a four second rest between each contraction, up to a maximum of ten repetitions. Next, the ability to perform fast strong contractions (Fast contractions) was tested. The subject was instructed to contract her PFM as fast and as strongly as she could (1 second contractions), up to a maximum of ten. The final three tasks examined if elevation of the pelvic floor and bladder neck was observed during a PFM contraction (Elevation), if the subject co-contracted the lower abdominal muscles during a PFM contraction (Co-contraction), and the timing of an involuntary PFM contraction with a cough (Timing of involuntary contraction). A short rest between tasks was given to the subjects while the instructions for the upcoming task were explained.
The physiotherapist was blind to the results of the EMG assessment until after the physical assessment. Ideally, the pelvic exam was to be arranged either before or after the EMG assessment depending on the availability of the clinician and subjects, in some cases (n=3) the pelvic exam was done between the two EMG testing sessions if scheduling conflicts were presented.

7.6 ABDOMINAL ELECTRODE LOCATIONS

![Figure 7-1: Electrode Placement]

1. Chest Wall (Thompson et al., 2006)
2. Rectus Abdominis 2 cm lateral and superior to the umbilicus (Ng et al., 1998)
3. External Obliques 12-15 cm lateral to the umbilicus (McGill et al., 1996)
4. Internal Obliques/Transversus Abdominis 2 cm medial and inferior to ASIS (Ng et al., 1998)
5. PFM Wire Electrode Leads
6. Reference Electrodes for monopolar surface electrodes Right and Left iliac crest
7. Reference Electrode for bipolar electrodes Left ASIS