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# Postural and Respiratory Functions of the Pelvic Floor Muscles

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**Aims:** Due to their contribution to modulation of intra-abdominal pressure (IAP) and stiffness of the sacroiliac joints, the pelvic floor muscles (PFM) have been argued to provide a contribution to control of the lumbar spine and pelvis. Furthermore, as IAP is modulated during respiration this is likely to be accompanied by changes in PFM activity. **Methods:** In order to evaluate the postural and respiratory function of the PFM, recordings of anal and vaginal electromyographic activity (EMG) were made with surface electrodes during single and repetitive arm movements that challenge the stability of the spine. EMG recordings were also made during respiratory tasks: quiet breathing and breathing with increased dead-space to induce hypercapnoea. **Results:** EMG activity of the PFM was increased in advance of deltoid muscle activity as a component of the pre-programmed anticipatory postural activity. This activity was independent of the direction of arm movement. During repetitive movements, PFM EMG was tonic with phasic bursts at the frequency of arm movement. This activity was related to the peak acceleration of the arm, and therefore the amplitude of the reactive forces imposed on the spine. Respiratory activity was observed for the anal and vaginal EMG and was primarily expiratory. When subjects moved the arm repetitively while breathing, PFM EMG was primarily modulated in association with arm movement with little respiratory modulation. **Conclusions:** This study provides evidence that the PFM contribute to both postural and respiratory functions. *Neurourol. Urodynam. 26:362–371, 2007.* © 2007 Wiley-Liss, Inc.

**Key words:** pelvic floor electromyography; postural control; respiration

## INTRODUCTION

The muscles of the pelvic floor (PFM) support the abdominal and pelvic viscera and are active tonically in standing and sitting.[1–3] Furthermore, because the abdomen is a fluid-filled cavity, intra-abdominal pressure (IAP) is distributed in all directions and the PFM, which form the floor of the abdominal cavity, contribute to its control. During periods of increased IAP, such as coughing[4] or lifting,[5] PFM activity is increased to prevent or limit rostral displacement of the floor, maintain the position of the bladder neck,[6] and assist with urethral and anal closure.[7–8] As a result of this contribution to control of IAP, the PFM are likely to contribute to control of the spine and pelvis. Furthermore, PFM activity may also indirectly contribute to lumbopelvic control via an effect on tension developed in the thoracolumbar fascia; hoop tension of the fascia from contraction of the abdominal muscles is dependent on IAP.[9] Finally, simulated contraction of the PFM has been shown in vitro to increase the stiffness of the sacroiliac joints in women.[10]

Recent human[11] and porcine[12] studies confirm that IAP increases spinal stiffness and controls intervertebral motion. It is well known that muscles that surround the abdominal cavity, such as the diaphragm[13,14] and abdominal muscles,[15,16] are active in association with tasks that challenge spinal stability. When such challenges are predictable, activity of these muscles is initiated in advance of the perturbation and are pre-programmed by the nervous system.[17] Although spinal and cortical[18] mechanisms for control of the PFM have been studied, it is not known whether the nervous system activates the PFM as part of these anticipatory postural adjustments.

PFM are also likely to be active with respiratory tasks. It is well accepted that PFM activity accompanies coughing[2,19] and resisted expiration.[2,20] However, as IAP is modulated during the respiratory cycle,[21,22] it is likely that PFM activity may be modulated during other respiratory tasks, including quiet breathing. To further complicate this control, respiratory and postural activity of the muscles that surround the abdominal cavity must be coordinated. Recent studies indicate that during tasks that challenge the spine in a sustained manner, such as repetitive limb movements, tonic postural activity of the diaphragm, and transversus abdominis is modulated phasically at the frequencies of respiration and arm movements.[14,23] Whether PFM activity is coordinated in a similar manner has not been investigated.

The aims of this study were to investigate: (1) whether PFM contribute to the pre-programmed postural activity of the trunk muscles prior to predictable challenges to spinal stability; (2) whether this response, if present, is dependent on the direction of reactive moments; (3) whether postural activity of the PFM is sustained during a prolonged postural task, (4) whether PFM activity is related to the magnitude of reactive moment; (5) whether PFM activity is modulated during respiratory tasks; and (6) whether postural and respiratory activities of the PFM can be coordinated. Preliminary data has been presented as an abstract.[24]

## METHODS

### Subjects

EMG recordings were made from PFM in one male and six females. The mean (range) age, height, and weight of the female subjects were 45.7 (35–63) yr, 1.66 (1.60–1.73) m, and 59 (54–61) kg, respectively. The age, height, and weight of the male subject were 30 yr, 1.82 m, and 85 kg, respectively. Subjects were excluded if they had a history of neurological or respiratory disorder or a history of back pain that had limited

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function. Of the female subjects, one subject was nulliparous and the remainder had between 2 and 4 normal vaginal deliveries. No subjects experienced clinical urinary incontinence. The single male subject was included to provide preliminary data whether PFM respond in a similar manner in males and females. All procedures were undertaken according to the Declaration of Helsinki.

### Electromyography

Electromyographic (EMG) recordings were made from the PFM in the female subjects using surface electrodes inserted into the vagina (Periform Intra-Vaginal Probe, NEEN HealthCare, England, UK) (Fig. 1). In all females and the male subject, EMG recordings were also made from a pair of pre-gelled disposable surface electrodes (Medtronic, Minneapolis, MN) inserted into the anus and attached laterally to the anal mucosa (Fig. 1). These electrodes are considered to make recordings primarily from the external anal sphincter.[25] In order to examine whether cross-talk from the hip and abdominal muscles[26,27] would interfere with the PFM recordings with contractions of the intensity used in this experiment, an additional experiment was conducted ($n = 1$) in which recordings were made from the PFM with a vaginal electrode, and activity of the gluteus maximus, hip adductors, medial hamstrings, obliquus internus abdominis, and rectus femoris was recorded with surface EMG electrodes during contractions of each of the muscles at the intensity recorded during the arm movement task (see below). The subject was provided with feedback of EMG amplitude on an oscilloscope and was instructed to match the target, separately for each muscle, while maintaining the PFM relaxed. Raw data in Figure 1 shows that with contractions of this intensity, there was no cross-talk from the hip and abdominal muscles recorded with the vaginal electrode. As the purpose of this study was to evaluate PFM activity during low force tasks, this data confirms that cross-talk is unlikely to have contributed to the recorded EMG changes. However, it is likely that cross-talk from other adjacent components of the PFM group contribute to the signal. Therefore, we refer to recordings of PFM as either anal or vaginal EMG rather than relating the activity to a specific muscle.

Disposable Ag/AgCl disc electrodes (10 mm diameter, 20 mm inter-electrode distance, Conmed, Utica, NY) were fixed to the skin over the right lumbar erector spine (ES) adjacent to L4, over the right lateral abdominal muscles midway between the rib cage and iliac crest and over the anterior and posterior portions of the left deltoid. Recordings were made from transversus abdominis in one subject using bipolar fine-wire electrodes (75 mm diameter Telfon-coated stainless-steel wire with 1 mm of insulation removed) inserted under the guidance of ultrasound imaging.[16] EMG data were bandpass filtered between 53 Hz and 1 kHz and sampled at 2 kHz using a Power1401 and Spike 2 software (Cambridge Electronic Design, Cambridge, UK).

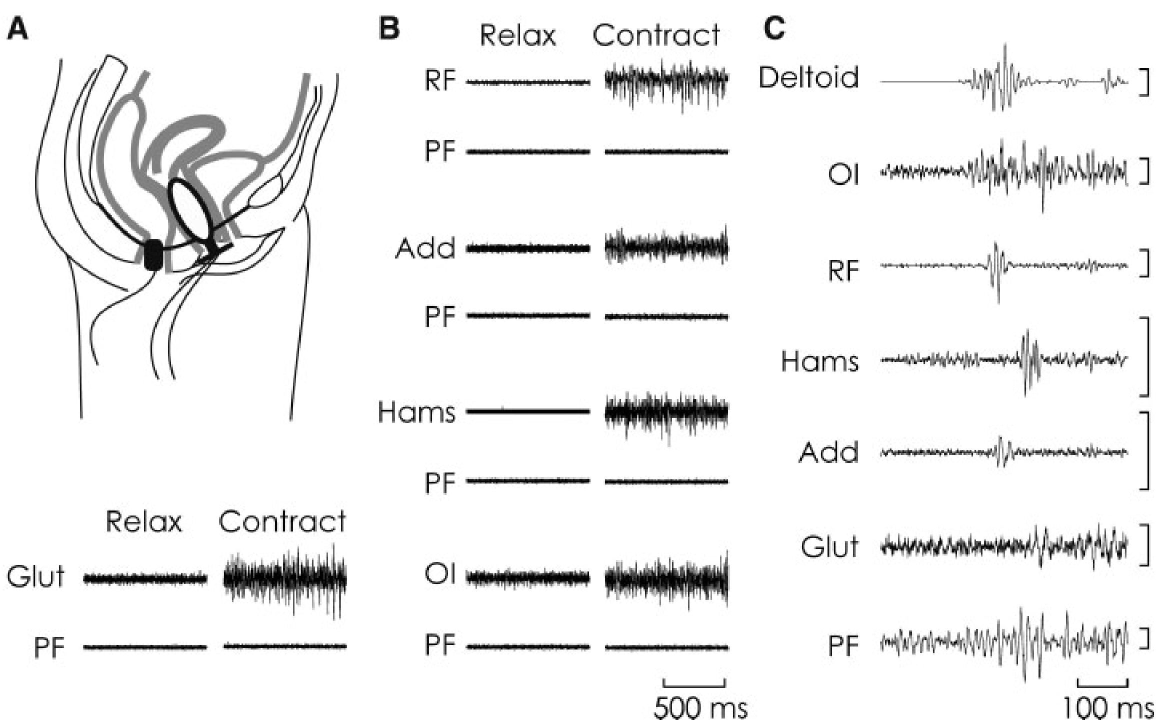


**Fig. 1.** Surface EMG of PFM. **A**: Location of the vaginal and anal EMG electrodes. The vaginal electrode was situated transversely right to left and the anal electrodes were placed on the right and left anal wall. **B**: Activity recorded with the vaginal EMG (PF) electrode during submaximal contraction of the hip (gluteus maximus: Glut, rectus femoris: RF, hip adductors: Add, hamstrings: Hams) and abdominal (obliquus internus abdominis: OI) muscles during contraction of each muscle while attempting to maintain relaxation of the PFM. **C**: Activity recorded during a single repetition of shoulder flexion. Amplitude of EMG activity recorded during this task was used to guide the level of contraction in the voluntary tasks in B. EMG calibration deltoid: 1 mV, EMG calibration trunk muscles: 100 μV.

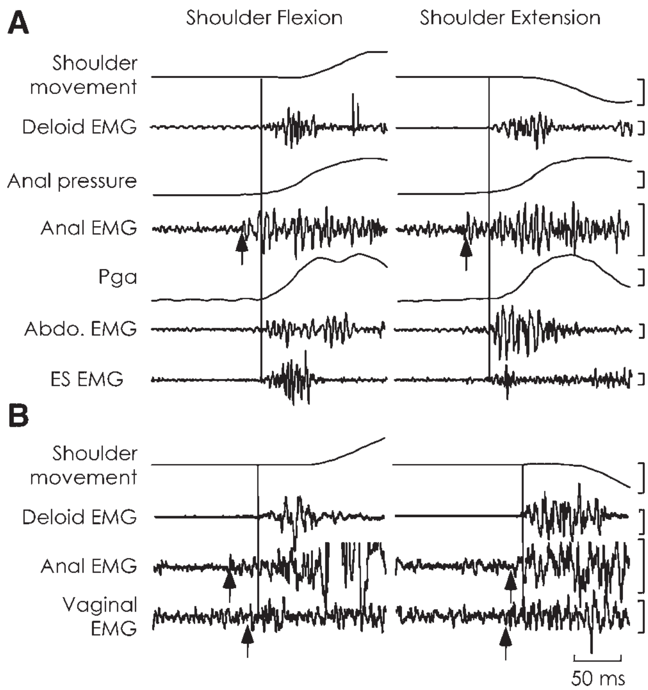


**Fig. 2.** EMG activity during single arm movements. EMG activity is shown for a representative male (**A**) and female (**B**) subject for single repetitions of shoulder flexion and extension. Solid lines indicate the onset of deltoid EMG and arrows indicate the onset of activity recorded with the anal and vaginal EMG electrodes. Intra-abdominal pressure (Pga) and anal pressure are shown for the male subject. EMG calibration: 2 mV, pressure calibration: 5 $cmH_2O$, shoulder movement calibration: 60°. Abdo—abdominal, ES—erector spinae.

### Procedure

Subjects performed a series of arm movement and respiratory tasks in standing with the feet shoulder width apart. The tasks were:

(i) *Single repetitions of shoulder flexion or extension in response to a light*. Movement was performed to ~45° in either direction. Subjects stood relaxed and moved the left arm as fast as possible in response to the light. Emphasis was placed on the speed of displacement. Subjects performed 10 repetitions in each direction with a 20 sec rest between repetitions. Movement of the arm was measured with a potentiometer attached to the arm via a lightweight rod and wrist strap with the axis aligned to the center of rotation of the glenohumeral joint.

(ii) *Repetitive movement*. Subjects repetitively and rapidly moved the arm around the shoulder joint between 15° forwards and backwards. Movement was performed as fast as possible for 10–15 sec with the breath held at the end of a normal relaxed expiration.

(iii) *Repetitive movement with increasing frequency*. Subjects moved the arm repetitively as described above, but the frequency of movement started at 1 Hz and was increased over 10 sec until movement was performed as fast as possible.

(iv) *Quiet breathing*. Subjects breathed quietly through a pneumotachometer (Hans Rudolf, Kansas City, MO). Subjects were not given feedback of breathing and recordings were made for 60 sec.

(v) *Increased dead space breathing.* Subjects breathed through a tube (volume: ~2 L) for 3 min to induce hypercapnia and recordings were made during the third minute when tidal volume ($V_T$) reached a steady state.

(vi) *Repetitive movement with breathing.* Arm movement was performed repetitively (10–15 sec) as described above, except subjects were instructed to maintain breathing during the movement.

### Additional Measurements

Measurement of gastric pressure (IAP) were made using a pressure transducer inserted via the nose into the stomach (Gaeltec Ltd, Isle of Skye, Scotland) and anal pressure using a pressure balloon inserted into the anus (Hollister, Inc., Libertyville, IL) in two subjects (one male, one female). The anal balloon was inflated after insertion and was held in place with an elastic strap.

### Data Analysis

For single arm movements, the onset of EMG was identified from raw EMG traces that were presented individually and at random without reference to muscle or other temporal events. In a number of trials, EMG onsets were difficult to select due to the ongoing background EMG of the PFM and the accuracy of EMG onset detection was improved by rectification and averaging the data, triggered from the onset of deltoid EMG. EMG onsets were then selected from the averaged trials and calculated relative to the onset of deltoid EMG.

Data for the repetitive movements were analyzed in the frequency and time domains. In the frequency domain, the relationship between EMG and movement data was analyzed from the presence of peaks in the power spectra and the coherence between these signals at the frequency of arm movement. The power spectral densities of the auto-correlations of the EMG and movement data were calculated to identify the frequency of EMG bursts and the frequency of shoulder motion.[14] To remove any non-stationarity from the data due to low-frequency drift, and to remove any movement artifact, EMG data were high-pass filtered at 100 Hz (4th order zero-lag Butterworth filter) and then rectified and low-pass filtered at 30 Hz.[14] As the high-frequency components within the multi-unit EMG were removed, only the low-frequency EMG bursts in association with the shoulder movement and respiration were evaluated. Peaks in the power spectra were identified visually with each trace displayed individually in a blinded manner. The correlation between the movement and EMG data was quantified as the coherence between these data at the frequency of arm movement. A coherence of 1 indicates a perfect relationship between the amplitude and the phase of the signals at that frequency. For trials with movement and breathing, rib cage movement was treated in the same manner as described for the arm data and coherence was measured at the frequencies of arm movement and breathing.

In the time domain, averages of anal, vaginal, erector spine abdominal, and deltoid EMG were triggered from the onsets of shoulder flexion identified from the arm movement. The number of repetitions varied between subjects depending on the arm movement frequency. Peaks in activity associated with each arm movement and the presence of ongoing tonic activity were confirmed from these averages. In the two subjects with recordings of IAP, these data were also averaged.

In trials with arm movement at increasing frequency, the relationship between shoulder acceleration and amplitude of EMG or pressure were assessed with Pearson's correlation coefficient between peak shoulder acceleration for consecutive arm movements and the corresponding RMS EMG or pressure (measured over a 100 msec-epoch).

For comparison of PFM, abdominal and erector spine EMG between inspiration and expiration, EMG data were rectified and averages were trigged from the peak of inspiration. The mean EMG amplitude for the last 1-sec of the expiratory and inspiratory phases was calculated. The baseline noise, calculated from recordings made with the subject in supine, was subtracted and respiratory data were expressed as a proportion of EMG recorded during the maximal PFM contractions.

### Statistical Analysis

EMG onset of each muscle was compared between directions of movement using a repeated-measures analysis of variance (ANOVA) with one repeated measure (direction) and one independent factor (muscle). In a similar manner, EMG amplitude was compared between inspiration and expiration using a repeated-measures ANOVA. Coherence between arm movement and EMG at the frequency of arm movement was compared between trials with and without breathing using a repeated-measures ANOVA. When the main effect or interaction was significant, post-hoc testing was undertaken with Duncan's multiple range test. Alpha level was set at 0.05.

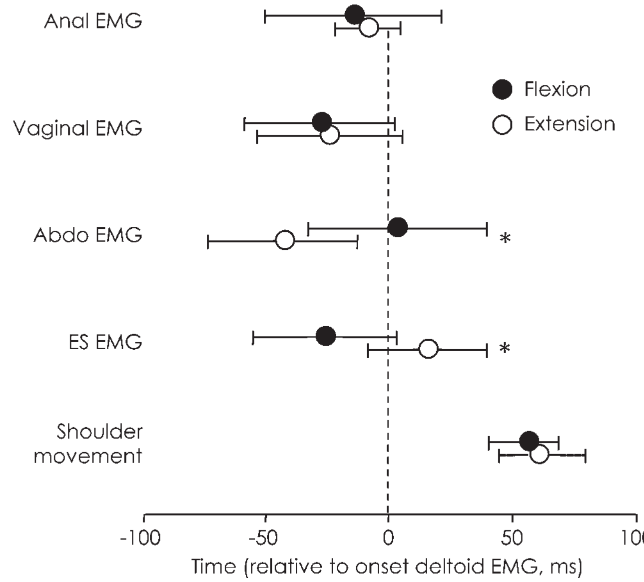


**Fig. 3.** Mean EMG onsets during single arm movements. Onset of the pelvic floor and trunk muscles is shown relative to the onset of deltoid EMG (dashed line at 0 msec) for flexion and extension of the arm. Onset of activity recorded with the anal and vaginal electrodes did not vary between the directions of arm movement. Abdo—abdominal, ES—erector spinae.

## RESULTS

### PFM Activity With Rapid Arm Movements

In standing, low-level tonic activity of the PFM was recorded with the anal and vaginal EMG electrodes. When subjects moved their arms forwards or backwards, anal and vaginal EMG increased in advance of deltoid EMG (Fig. 2). As activity recorded with the anal electrode was qualitatively similar for the male and female subjects, data were pooled for analysis. With shoulder flexion, an increase in EMG activity was recorded with the vaginal electrode 28.4 (30) msec before the onset of deltoid EMG and activity was recorded with the anal electrode 15.1 (36) msec before deltoid. The onset of EMG activity recorded with the anal and vaginal electrodes was not different between directions of movement of the arm (anal: $P = 0.63$; vaginal: $P = 0.62$) (Fig. 3). In contrast, ES EMG was initiated earlier during shoulder flexion than extension ($P < 0.02$), and abdominal EMG was initiated earlier during shoulder extension compared to shoulder flexion ($P < 0.003$).

Figure 2 shows that anal pressure began to increase prior to the onset of arm movement and IAP increased either at the same time or slightly after the increase in anal pressure. The onset of IAP increase after the onset of anal pressure indicates that the anal pressure increase was not simply due to transmission of pressure from the abdominal cavity.

### PFM Activity With Repetitive Arm Movements

During repetitive arm movements, the PFM were tonically active throughout the arm movement cycle. Raw data from representative female and male subjects are shown in Figure 4. Bursts of anal and vaginal EMG activity can been seen in association with each arm movement. Peaks in the EMG power spectra were identified in all muscles at the frequency of arm movement. The power spectra of the shoulder movement data in Figure 5 show peaks between 2.4 to 4.0 Hz, representing the frequency of arm movement.

In female subjects, there was a peak in the power spectra of vaginal EMG at 2.7 (0.3) Hz, which was associated with arm movement at 2.7 (0.3) Hz. For female subjects, a peak in the anal EMG spectra was also identified at 2.8 (0.3) Hz. The male subject had a peak in the anal EMG spectra at 4.0 Hz which corresponded to an arm movement peak at 4.0 Hz. In one subject, a larger peak in the power spectra of the anal and vaginal EMG was present at double the frequency of arm movement, consistent with a biphasic response in association with each arm movement cycle. Consistent with the power spectra data, at the frequency of arm movement, the coherence between arm movement and anal, vaginal, abdominal, and ES EMG indicated a strong relationship of 0.45 to 0.60 (Table I).

Averages of the rectified EMG, triggered from the peak of shoulder flexion, present similar findings to the spectral data (Fig. 5). The upper panel of Figure 5 shows the recordings from the male subject, and lower panels shown two representative female subjects. Modulation of EMG activity is apparent for PFM, ES, and abdominal muscles. However, as shown in Figure 5, the timing PFM EMG peaks differed between individual subjects. For instance, panel C shows a biphasic pattern of PFM EMG, whereas panel B shows a monophasic pattern. Phasic modulation of IAP and anal pressure can also be observed in Figure 5A.

In order to confirm that PFM EMG was related to the reactive forces from limb movement, the relationship between the peak acceleration of the arm (i.e., reactive moment) and the EMG amplitude was calculated for tasks in which subjects moved the arm repetitively with increasing frequency. Representative data for a female and male subject are shown in Figures 6 and 7. The correlation between PFM EMG amplitude and the peak acceleration of the arm was significant for all subjects (Table II).

### PFM Activity During Respiratory Tasks

When subjects breathed quietly ($V_T$: 0.7 (0.1) L), there was modulation of PFM EMG in standing. All but one female

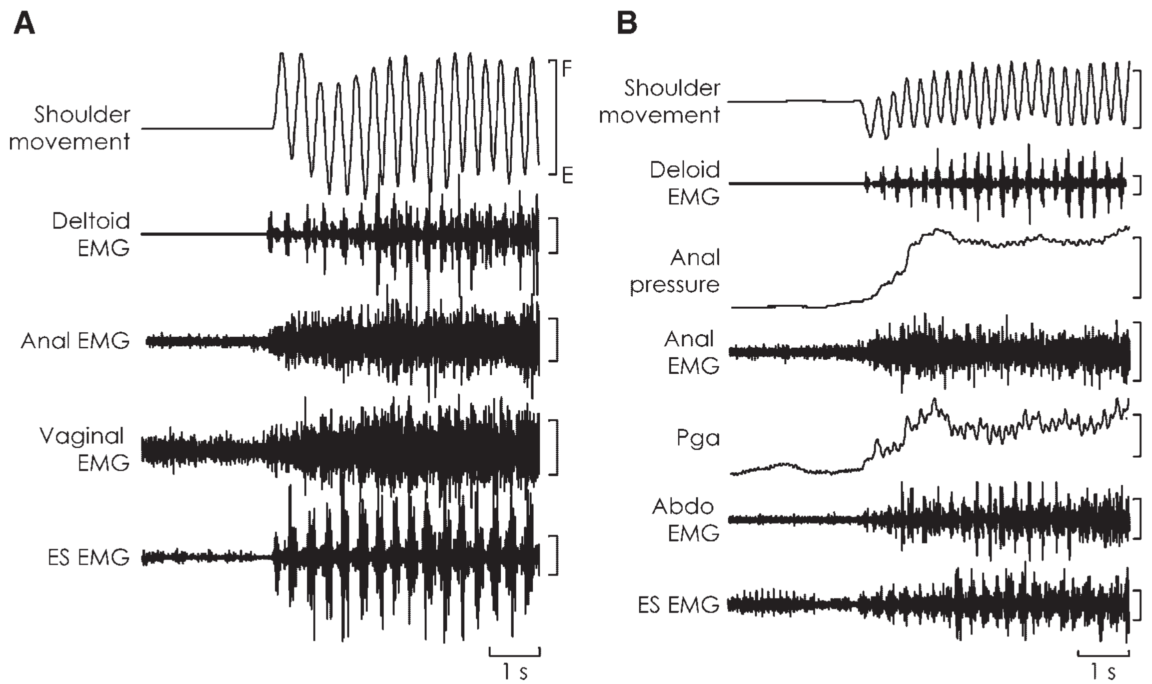


**Fig. 4.** EMG activity during repetitive arm movements. Data are shown for a representative female (**A**) and male (**B**) subject. Intra-abdominal pressure (Pga) and anal pressure are shown for the male subject. Activity recorded with the anal and vaginal EMG electrode are tonically active during the repetitive arm movement, whereas abdominal (Abdo) and erector spinae (ES) EMG is modulated phasically. EMG calibration: 2 mV, pressure calibration: 10 cm$H_2O$. F—flexion, E—extension.

subject had greater vaginal EMG during expiration compared to inspiration and there was a significant difference between activity recorded during the last 1 sec of inspiration and expiration (Expiration: 5.7 (3.6) % MVC, inspiration: 0.1 (0.1) % MVC, $P < 0.03$) (Figs. 8 and 9). In contrast, anal EMG was more variable and there was no difference in anal EMG between respiratory phases for the group (Expiration: 0.3 (0.4) % MVC, inspiration: 1.1 (1.3) % MVC, $P = 0.09$)(Figs. 8 and 9). When tidal volume was increased ($V_T$: 2.1 (0.3) L) by breathing with increased dead-space for 90 sec, PFM EMG was increased during both respiratory phases compared to quiet breathing, but was greater during expiration ($P < 0.0001$). Vaginal EMG increased to 19.1 (11.0) % MVC during expiration and 12.8 (7.1) % MVC during inspiration ($P < 0.03$). Anal EMG increased to 8.9 (6.5) % MVC during expiration, and 6.9 (6.0) % MVC during inspiration ($P < 0.002$). Across tasks respiratory activity recorded with the vaginal electrode was greater than that recorded with the anal electrode ($P < 0.01$). Activity of the abdominal muscles was greatest during expiration ($P < 0.05$) during both quiet breathing and breathing with hypercapnoea. In contrast, ES activity was greatest during inspiration ($P < 0.02$).

As can be seen in Figure 9 during quiet breathing, IAP increased during inspiration. However, during hypercapnoea, IAP was increased during both phases, but to a greater extent during inspiration. Thus, PFM activity was not linked to the respiratory phase with greatest IAP, but with the phase in which abdominal muscle activity was increased.

When an arm was moved repetitively during breathing, peaks were present in the power spectra at the frequency of arm movement (2.9 (0.5) Hz) and respiration (0.5 (0.1) Hz). Furthermore, the coherence between arm movement and EMG was high at the frequency of arm movement and was not different to that reported for the trials in which arm movement was performed without breathing (Table I; $P > 0.11$). In contrast, the coherence between rib cage motion and EMG of all muscles at the frequency of respiration was low (0.08–0.18) (Table II), indicating that there was little modulation of EMG amplitude coupled to respiration.

## DISCUSSION

The results of this study confirm that PFM contribute to the postural response associated with arm movements. That is, these muscles are active as a component of the pre-programmed postural adjustment that prepares the body for predictable perturbations. Furthermore, PFM activity is tonic during a sustained postural task with modulation in amplitude related to the reactive moments at the trunk. The data also indicate that PFM activity is modulated during quiet breathing. However, this activity is more closely associated with activity of the abdominal muscles than with changes in IAP. Taken together, these data suggest that PFM are controlled by a number of integrated networks in the nervous system, but their activity is coordinated to perform multiple tasks concurrently.

### Methodological Considerations

A criticism of the EMG recordings used in this study is that it is not possible to identify the PFM that contribute to the signal. Other authors have suggested that cross-talk from hip and abdominal muscles may also contribute to the signal.[27] However, as can be seen in Figure 1, when the hip muscles are contracted at a similar magnitude to that recorded during arm movements, but with the PFM relaxed, no activity was

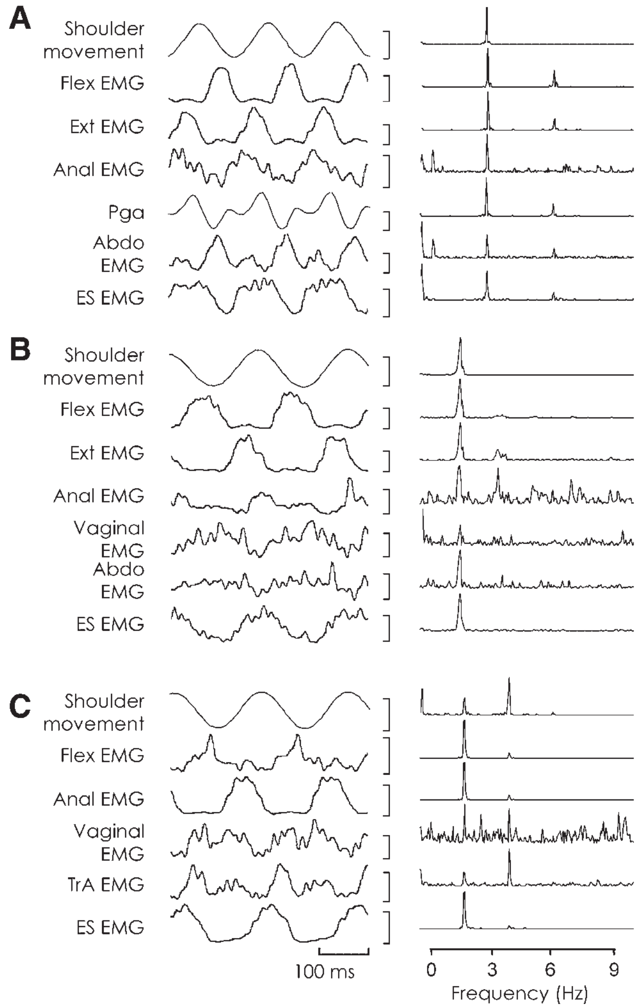


**Fig. 5.** Averages of EMG triggered from the arm movement data (**left**) and power spectral densities (**right**) of the EMG, pressure and movement data during repetitive arm movement trials. Data are shown for a representative male (**A**) and two female subjects (**B** and **C**). Averages, triggered from the onsets of flexion movement of the arm, show tonic activity recorded with the anal and vaginal electrodes with superimposed bursts of EMG activity in association with the arm movements. Intra-abdominal pressure data (Pga) show a biphasic increase in pressure with each arm movement cycle. EMG calibration: 2 mV, Pressure calibration: 10 cm$H_2O$, Power spectral density are normalized to peak power for each muscle. Abdo—abdominal, ES—erector spinae, TrA—transversus abdominis.

recorded with the vaginal electrode. Although cross-talk from adjacent hip muscles may contaminate the recording with higher amplitude contractions,[27] we are confident that under the present conditions, our recordings reflect activity of the PFM. This is supported by other studies that report poor correlation between PFM and abdominal EMG activity using electrodes similar to those used here.[28] A problem with earlier studies that have reported cross-talk from hip or abdominal muscles with vaginal EMG recordings is that activity of the PFM generally accompanies contraction of these muscles[19,26,27] potentially leading to erroneous interpretation of cross-talk.

**TABLE I. Coherence Between EMG and Rib Cage or Movement Data**

| Muscle | Coherence to arm at movement frequency: no breathing trials | Coherence to arm at movement frequency: breathing trials | Coherence to rib cage movement at respiratory frequency |
|---|---|---|---|
| Anal EMG | 0.56 (0.23) | 0.48 (0.21) | 0.08 (0.04) |
| Vaginal EMG | 0.45 (0.30) | 0.29 (0.05) | 0.18 (0.14) |
| Abdo EMG | 0.59 (0.25) | 0.53 (0.25) | 0.12 (0.11) |
| ES EMG | 0.60 (0.30) | 0.70 (0.19) | 0.14 (0.14) |

ES, erector spinae; Abdo, abdominal; EMG, electromyography.

**PFM Activity Contributes to Postural Control of the Trunk**

As predicted, PFM activity was initiated as part of the anticipatory postural adjustment associated with arm movement. These responses involve activity of muscles of the limbs and trunk and are matched to the demands for control of postural equilibrium and joint stability in association with predictable challenges to the body.[16,17,29,30] As the onset of activity of the trunk muscles (including PFM) precedes that of deltoid, these responses cannot be initiated in response to afferent input from the disturbance to the body and must therefore be pre-programmed by the nervous system.[17,29] Furthermore, as the increase in PFM activity preceded that of the abdominal muscles in shoulder flexion trials and preceded the increase in IAP, the increase in PFM activity cannot be explained by a reflex response to stretch of the PFM secondary to increased IAP from abdominal and diaphragm muscle activity. In a similar manner, previous studies have reported activation of the PFM before activation of the abdominal muscles during coughing.[31]

As IAP is increased as a result of activity of the abdominal[15,30] and diaphragm[23] muscles, it is predictable that PFM activity would be required to control the descent of the pelvic viscera and contribute to the control of the continence through control of the position of the bladder neck[32] and increased urethral pressure.[33] Thus PFM activity is not only required to meet the increased demands for control of continence, but also provides an essential contribution to the elevation of IAP. As recent studies confirm that IAP directly contributes to spinal control,[11,12] the current data suggest that PFM activity has a direct influence on control of the spine. Furthermore evidence that PFM stiffen the sacroiliac joints in women[10] suggests a contribution to pelvic control.

The timing of activity of the PFM was not dependent on the direction of movement of the arm, and therefore the direction of reactive moments. This non-direction specificity suggests that the PFM are required regardless of the nature of the forces. Consistent with this proposal, previous studies have reported increased IAP with movements of the arm[30] or support surface[34] in multiple directions. Furthermore, with movement of the arm in both directions, anal pressure increased prior to the onset of arm movement. This confirms that the mechanical response of PFM contraction was sufficiently early to precede the reactive forces from arm movement, regardless of movement direction.

PFM activity was also recorded during the repetitive arm movement task. This type of repetitive task is thought to involve reflex and pre-programmed components.[14,35] In general, activity recorded with the vaginal and anal electrodes was sustained (tonic) but with modulation of amplitude at the frequency of arm movement. The timing of peak activity varied between individuals, which is consistent with previous reports for the abdominal and diaphragm muscles.[23] The strong correlation between PFM activity and peak arm acceleration (i.e., reactive moments) provide further support for contribution of PFM to mechanical control of the spine.

Pre-programmed postural adjustments are known to be controlled by multiple regions in the nervous system including the motor cortex and pre-motor areas.[36,37] Although the PFM receive corticospinal inputs,[18] whether these are involved in organization of the postural activity of the PFM is unclear. Furthermore, in animals, nucleus retroambiguus, which contributes to control of IAP via inputs to the abdominal motoneurons, also innervates the motoneurons of the PFM, located in Onuf's nucleus in the sacral spinal cord.[38] Thus drive from multiple sources may contribute to the coordination of the postural activity of the muscles that surround the abdominal cavity.

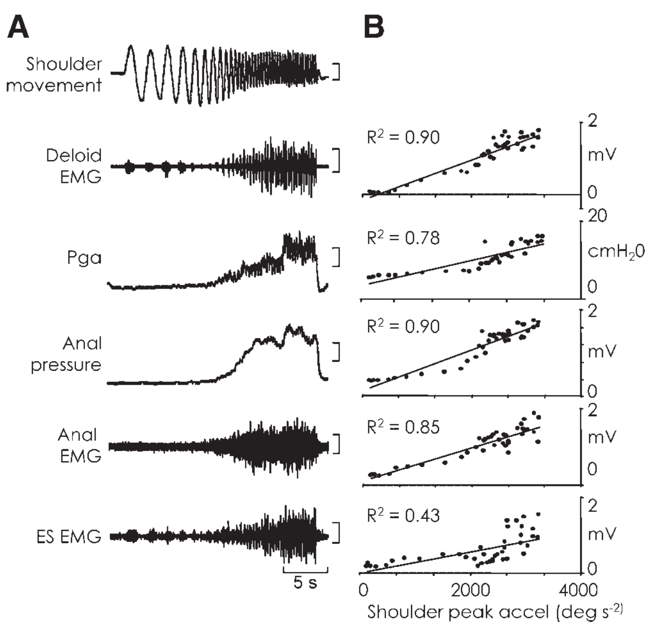


**Fig. 6.** EMG activity and pressure with repetitive arm movement at increasing frequency for the male subject. EMG, intra-abdominal pressure (Pga), and anal pressure are presented (**A**) with correlation between EMG or pressure amplitude and peak acceleration of the arm (**B**). The increase in EMG and pressure were strongly correlated with the amplitude of the peak acceleration of the arm. EMG calibration—2 mV, pressure calibration: 10 cm$H_2O$, arm movement calibration—15°.

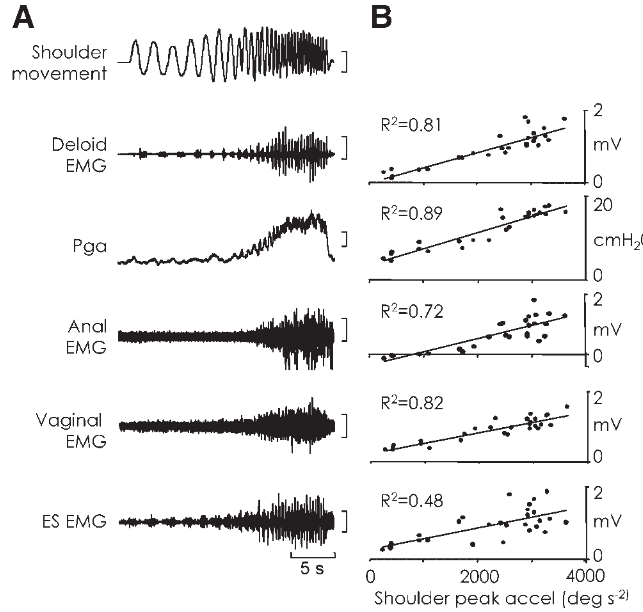


**Fig. 7.** EMG activity and pressure with repetitive arm movement at increasing frequency for a representative female subject. EMG and intra-abdominal pressure (Pga) are presented (**A**) with correlation between EMG or pressure amplitude and peak acceleration of the arm (**B**). The increase in EMG and pressure were strongly correlated with the amplitude of the peak acceleration of the arm. EMG calibration-: 2 mV, pressure calibration: 10 cm$H_2O$, arm movement calibration—15°.

**TABLE II. Correlation ($R^2$) Between Peak Shoulder Acceleration and EMG or Pressure Parameters**

| Subject | Vaginal EMG | Anal EMG | ES EMG | Abdominal EMG | Pga | Anal pressure |
|---|---|---|---|---|---|---|
| 1♀ | 0.82 | 0.91 | 0.62 | 0.84 | | |
| 2♀ | 0.65 | 0.89 | 0.75 | 0.51 | | |
| 3♀ | 0.87 | 0.74 | 0.53 | 0.73 | | |
| 4♀ | 0.82 | 0.72 | 0.48 | | 0.89 | |
| 5♀ | 0.39 | 0.71 | 0.39 | | | |
| 6♀ | 0.82 | 0.77 | 0.67 | 0.77 | | |
| 8♂ | | 0.85 | 0.43 | 0.61 | 0.78 | 0.90 |

ES, erector spinae; Pga, intra-abdominal pressure.

### Respiratory Activity of the PFM

During quiet breathing in standing, PFM activity was modulated with respiration. It was hypothesized that PFM activity would be linked to periods of increased IAP, to meet the demands of continence and control of pelvic viscera. During quiet breathing, IAP increases during inspiration in conjunction with diaphragm activity.[21] Thus inspiratory activity would be predicted. In the present study, vaginal EMG was greater during expiration, although activity was recorded during both respiratory phases. In contrast, anal EMG was more variable between subjects. When breathing is increased, IAP follows a biphasic pattern with peaks associated with diaphragm activity during inspiration and a smaller IAP increase associated with abdominal muscle activity during expiration.[21] In the present study when subjects breathed with hypercapnoea, although activity was increased during both phases, activity was always greater during expiration. Thus, contrary to the hypothesis, modulation of PFM EMG was invariably more strongly related to abdominal muscle EMG than to amplitude of IAP. This may be explained by a number of mechanisms. First, animal and human studies have identified co-activation of muscles surrounding the abdominal cavity during a range of maneuvers including stimulation of pelvic afferents[39] and voluntary contraction of the abdominal[26] or PFM.[19,40,41] Thus, co-activation may be obligatory. Second, although pressure in a fluid-filled cavity is distributed in all directions, due to hydrostatic effects IAP is greater in the base of the abdominal cavity. Thus coordinated activity of the PFM and abdominal muscles may be required to more directly influence the pelvic viscera.

Notably, activity of the PFM was sustained at an elevated level, without modulation with breathing during the repetitive arm movement task. In this task, elevated PFM activity, associated with sustained increase in IAP that has been reported previously[23] is likely to meet the joint demands for breathing and lumbopelvic control.

Although this is the first report of respiratory activity of the PFM during quiet breathing, activity has been reported in

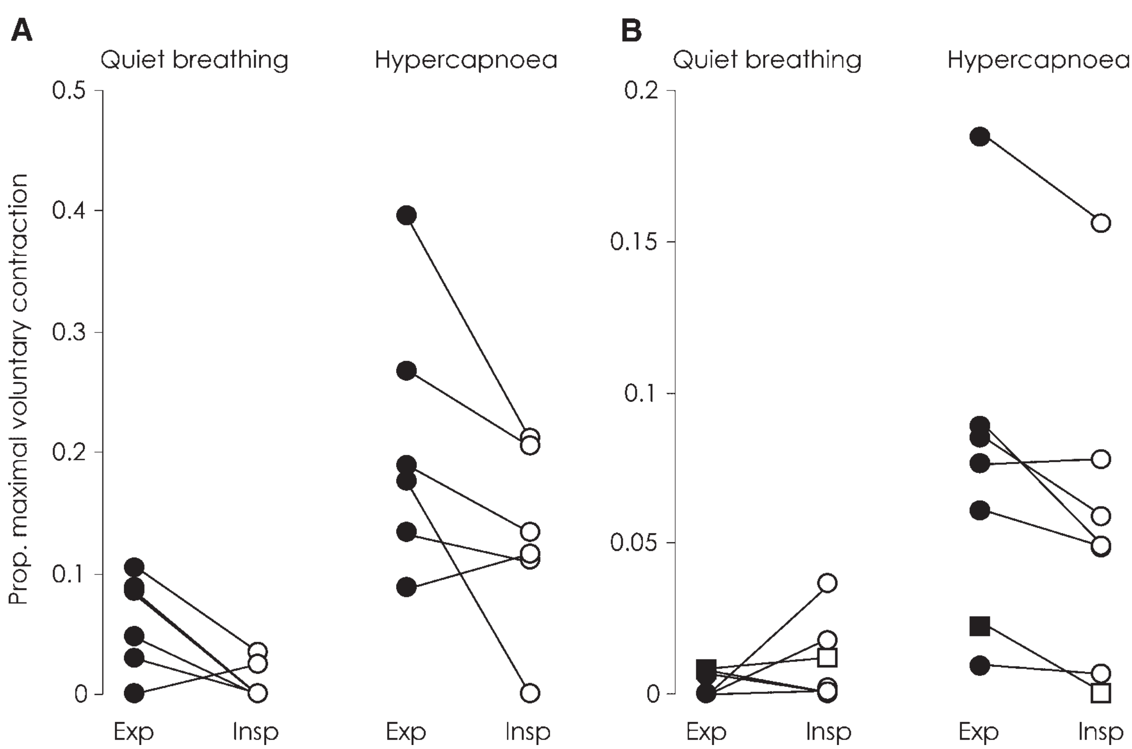


**Fig. 8.** Respiratory modulation of EMG activity with breathing. Root mean square EMG amplitude (normalized to maximum voluntary activity) for the last 1 sec during inspiration and expiration for individual subjects are shown for quiet breathing and hypercapnoea for EMG recorded with the vaginal (**A**) and anal (**B**) EMG electrodes.

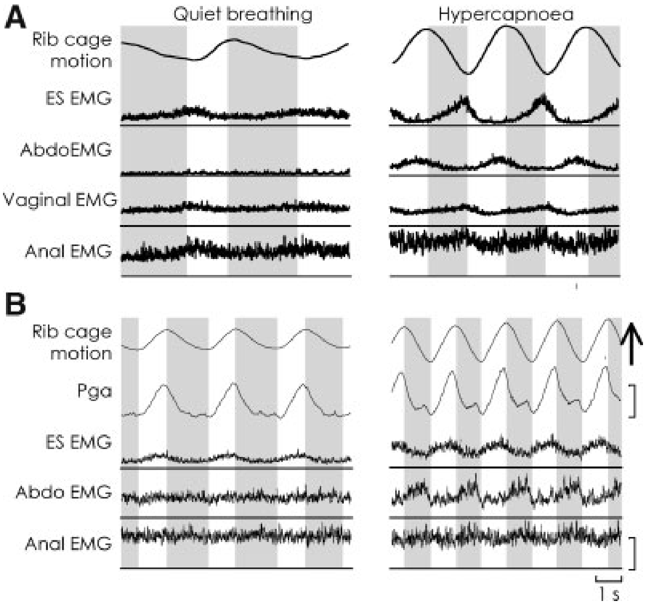


**Fig. 9.** Raw EMG data during quiet breathing and hypercapnoea. Data are shown for a representative female (**A**) and male (**B**) subject. Expiratory phase is indicated by the gray boxes. Activity recorded with the anal and vaginal electrodes increased during expiration and paralleled the activity of the abdominal (Abdo) muscles. EMG calibration—4 mV, pressure calibration—10 $cmH_2O$, inspiration is upwards. Pga—intra-abdominal pressure.

association with coughing,[33,42] sneezing and sniffing,[42] and forced expiration.[2,20] In these cases, it has been argued that the PFM activity is either pre-programmed[33] or mediated by a polysynaptic reflex.[42] As pressure in the urethra has been shown to increase ~200 msec prior to the increase in bladder pressure during a cough,[33] this supports a pre-programmed response.

Whether activity of the PFM is influenced by respiratory drive from the pontine and medullary respiratory nuclei, or whether respiratory activity is mediated by afferent input from muscle stretch[42] or stimulation of visceral afferents[39] is not possible to determine from the present study.

### Implications for Incontinence and Back and Pelvic Pain

As the muscles that surround the abdominal cavity contribute to continence, breathing, and spinal control, it is important to consider how these diverse functions can be coordinated. Although the present data suggest breathing, continence, and postural demands can be met under normal circumstances, this may not be possible when the demand on one or more of these systems is increased. For example, as PFM activity has been argued to be altered in stress incontinence,[43,44] this may be associated with compromised control of the spine and pelvis, potentially leading to development of pain. Data from several epidemiological studies;[45,46] suggest that back pain in more common in women with incontinence. Furthermore, data from a recent prospective longitudinal study suggest that women with incontinence, but no back pain have a greater probability of development of back pain over a period of 2–5 years.[47] In pregnancy, which imposes considerable challenge to the PFM, incidence of back pain during pregnancy is strongly related to incontinence.[48] Finally, high incidence of back pain and incontinence has been reported in females with cystic fibrosis,[49] although this is likely to be related to periods of high pressure with coughing. However, PFM descent[50] and paradoxical inhibition of the PFM[2] has been associated with coughing in women with stress urinary incontinence.

Studies of women with pelvic pain have reported similar findings. For instance, women with pelvic pain have increased descent of the PFM (measured with ultrasound imaging) and shallow breathing when lifting a leg in supine.[51] In that study, when the pelvis was stabilized externally, tidal volume increased and pelvic descent was reduced. Furthermore, women with pelvic girdle pain often report voiding dysfunction.[51,52] Thus coordination of the muscles that surround the abdominal cavity may be affected by changes in any one of the three key functions.

## CONCLUSION

This study provides initial evidence that the PFM contribute to both postural and respiratory functions and are likely to receive drive from multiple sites in the nervous system. Due to the contribution of these muscles to the canister that surrounds the abdominal cavity, these functions provide an important contribution to the coordination of postural, continence, and respiratory functions and may help explain the link between continence and back pain. Further studies are required to investigate the postural and respiratory functions of the PFM in women with incontinence and back pain.

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