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REVIEW ARTICLE

Pelvic floor muscle activity during impact activities in continent and incontinent women: a systematic review

Helene Moser[1,2] · **Monika Leitner**[1] · **Jean-Pierre Baeyens**[2] · **Lorenz Radlinger**[1]

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Abstract

Introduction and hypothesis Investigating the activity of the pelvic floor muscles (PFMs) in women during impact activities such as jumping, running or coughing may elucidate different aspects of PFM activation and therefore clarify the pathophysiology of stress urinary incontinence (SUI). A systematic review (PROSPERO 2016:CRD42016035624) was conducted to summarize current evidence on PFM activity during impact activities in both continent and incontinent women.

Methods PubMed, EMBASE, Cochrane, and SPORTDiscus databases were systematically searched for studies published up to December 2016. The PICO approach (patient, intervention, comparison, outcome) was used to construct the search queries. Original studies were included that investigated PFM activity during impact activities if they included terms related to muscle activity and measurement methods, test positions, activities performed and continence status. Two reviewers screened titles and abstracts independently to ascertain if the included studies fulfilled the inclusion criteria, and extracted data on outcome parameters.

Results The search revealed 28 studies that fulfilled the inclusion criteria, of which 26 were cross-sectional studies. They used different electromyography measurement methods, test activities, test positions, and comparisons with other structures. Ten studies compared continent and incontinent women. The timing of PFM activity in relation to the activity of other trunk muscles seems to be a crucial factor in maintaining continence. Women with SUI have delayed PFM activity.

Conclusions The findings of this systematic review suggest that impact activities causing involuntary and reflex PFM activity should be the subject of further study. This may help guide clinical studies to improve our understanding of how the PFMs react during impact activities and to determine best practices that can be included in rehabilitation programmes.

Keywords Cough · Electromyography · Exercise · Female · Pelvis · Stress urinary incontinence

Abbreviations

PFMs	Pelvic floor muscles
EAS	External anal sphincter
SUI	Stress urinary incontinence
EMG	Electromyography
NOS	Newcastle-Ottawa scale
MVC	Maximum voluntary contractions
RMS	Root mean square

Introduction

Stress urinary incontinence (SUI) is defined as the complaint of involuntary loss of urine on effort or physical exertion (e.g.

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✉ Helene Moser
helene.moser@vub.ac.be

[1] Applied Research & Development Physiotherapy, Section of Health, Bern University of Applied Sciences, Effingerstrasse 6, 3011 Bern, Switzerland

[2] Faculty of Physical Education & Physiotherapy, Vrije Universiteit Brussel, Brussels, Belgium

sporting activities), or on sneezing or coughing [1]. It is the most common form of urinary incontinence, affecting women of all ages [2]. SUI is especially frequent during exercise, and is more prevalent in women who engage in high-impact activities. Urine loss during sporting activities remains under-reported and can lead women to abandon physical activity [3]. In view of the fact that SUI represents a high social burden, it seems crucial to identify potentially modifiable risk factors such as impact activitites, including jumping, running, coughing and sneezing [4]. Constantinou et al. described a fast-acting contraction in the distal third of the urethra that contributes to the compressive forces on the proximal urethra that prevent urine loss [4]. Contraction of the pelvic floor muscles (PFMs; iliococcygeus, pubovisceral and puborectalis muscles, cephalad to the external anal sphincter, EAS) can stabilize the bladder neck and increase intraurethral pressure, which contributes to continence, especially when intraabdominal pressure is increased during, for example, coughing, sneezing and high-impact activities [4–8]. Furthermore, in view of the fact that PFM training is considered the first-line treatment for SUI, it may be worthwhile to investigate PFM activity during impact activities [2].

Since urethral closure pressure is one of the main factors maintaining continence, especially during impact activities, and recruitment of the urethral sphincter muscle plays a secondary role in maintaining continence [9], in this systematic review the focus was placed on the PFMs, and studies investigating only the urethral sphincter were excluded. The constant baseline activity of PFMs is analogous to the continuous activity of the EAS; therefore studies performed on the EAS were included [10]. Furthermore, given that surface electromyography (EMG) was used to measure EAS activity, potential overlap with the PFMs could not be excluded. As far as we can determine, no systematic literature review has been undertaken concerning PFM activity during impact activities.

The aims of this study were to evaluate evidence on PFM and EAS activity in women, to evaluate methods of measurement, test positions and different impact activities in continent and incontinent women, and to elucidate the timing of PFM contractions, the forms of contraction in PFM activity and the relationship between PFMs and other structures during impact activities.

Materials and methods

This systematic review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [11]. The review search strategy, methods of analysis, and inclusion criteria were established a priori and published in the PROSPERO international prospective register of systematic reviews in health and social care (2016: CRD42016035624; www.crd.york.ac.uk/prospero). Our search algorithm was peer reviewed by an academic colleague (L.R.) and was based on the guidelines developed by Sampson et al. [12].

Eligibility criteria and search strategy

The electronic databases of Cochrane, EMBASE and MEDLINE were searched for studies including female participants, aged 19 to 64 years. The acronym PICO (Population Intervention Comparison Outcome) was applied because it is known to be able to adequately develop a relevant review question for systematic literature research [13]. The final systematic search was run on 1 December 2016. The PICO approach was also used to look for studies in the SPORTDiscus and Google Scholar databases, and reference lists of articles were scanned to find other articles on the topic. No restrictions as to language or study design were applied. The PICO-based search strategy included muscle activity terms including muscle action, pelvic floor muscle activity, electromyography, reflex activity and pelvic floor muscle contraction, and combined them with measurement methods (e.g. vaginal surface EMG, needle EMG, anal surface EMG), test positions (e.g. standing, sitting, lying), and activities (e.g. coughing, running; Table 1). The entire electronic search strategy can be found online in the appendix (Electronic supplementary material).

Inclusion and exclusion criteria to assess eligibility were determined in advance (Table 1). Two researchers who worked on the review (H.M. and M.L.) independently screened the titles and abstracts of the studies found. Disagreements wee resolved by discussion to achieve consensus. These researchers independently assessed the full-text articles for eligibility based on the procedure described above.

Quality assessment and data extraction

The Newcastle-Ottawa scale (NOS; www.ohri.ca/programs/clinical_epidemiology/oxford.asp) was used to assess the methodological quality of the included observational studies [14]. For the case-control studies, the NOS for case-control studies was used, and for the cross-sectional studies the NOS as adapted for cross-sectional studies was used. The literature review was assessed using AMSTAR, a measurement tool to assess the methodological quality of systematic reviews (www.amstar.ca). The NOS for case-control studies consists of eight multiple choice questions that address subject selection, comparability and exposure. High-quality responses earn a star, to a maximum of nine stars. The NOS adapted for cross-sectional studies consists of seven questions that address selection, comparability and outcome, to a maximum of ten stars. H.M. and M.L. independently rated all included articles. Discrepancies were resolved by discussion and with a third reviewer (L.R.) to achieve consensus. The same researchers used a customized data extraction form to independently extract data. The following data were extracted from the included

Table 1 Inclusion and exclusion criteria for title, abstract screening and full-text evaluation

PICO item	Inclusion	Exclusion
Population	Stress urinary incontinence, continence Female, women Pelvic floor, pelvic floor disorder, levator ani, anal sphincter	Faecal (anal) incontinence, cadaver, animals, diabetes, neurological disease, surgery (prolapse/incontinence), male, pregnancy, children
Intervention	Posture, work of breathing, respiration, coughing, muscle contraction, jogging, running, jumping, exercise, sports, physical effort, physical fitness, exercise movement techniques, exercise therapy, high-impact exercise, high-impact sport	
Comparison	Asymptomatic, continent and incontinent women, healthy volunteers	
Outcome	Biomechanics of pelvic floor, muscle action, muscle contraction, muscle function, contraction form, pelvic floor muscle activation, pelvic floor muscle contraction, mechanism of urinary continence, neuromuscular action, action potential, innervation frequency, recruitment, EMG, electromyography, reflex activity, muscle activity factor, refractory period, neural conduction, action potentials	

studies: study design, characteristics of the participants, type of EMG electrode and recording equipment, activities tested, test position and bladder filling, comparison of continent versus incontinent women, and outcome(s). Disagreements wee resolved by discussion to achieve consensus.

Data synthesis and analysis

The data extracted from the studies were very heterogeneous (as shown in Table 2). The analysis was therefore limited to a systematic review without a meta-analysis.

Results

Study selection

As shown in the study flow chart (Fig. 1), the literature search identified 1,717 abstracts. Of these 1,717 abstracts, 209 duplicate studies were removed and 1,471 abstracts were discarded following application of the inclusion and exclusion criteria, leaving 37 studies for full-text review. Of these 37 studies, 9 were excluded, mainly because they did not test impact activities; thus, 28 studies remained for inclusion in the systematic review. These remaining studies comprised 26 cross-sectional studies, 1 case-control study and 1 literature review. Ten studies compared continent and incontinent women.

Risk of bias within studies

The results of the assessments of the 26 cross-sectional studies for risk of bias are summarized in Table 3. The mean number of stars awarded was 5.2/10 (range 2 to 7). The studies included appropriate methods for assessing and statistically analysing their outcomes. The selection process was of poor quality in several studies, especially in terms of sample size and nonrespondent rate. The case-control study received the maximum score of nine stars on the NOS case-control scale, but the literature review received the minimum score of 0 out of 11 points in AMSTAR.

EMG electrodes

All studies used EMG measurements, but they applied different methods to different PFM structures. Vaginal EMG was performed in 13 studies with different types of probe, including Periform, Femiscan, DSE® (differential suction electrode), STIMPON and MAPLe (Multiple Array Probe Leiden). Surface EMG of the EAS was used in six studies, and of the perineum in one study. Needle and wire EMG of the bulbocavernosus, pubococcygeal and urethral wall muscles were used in seven studies.

EMG units

Different methods were used to express PFM EMG activities. In some studies PFM EMG activities were expressed as mean or maximal values in microvolts. In other studies PFM EMG activities were expressed as percentages: mean maximum voluntary contraction (MVC) values or mean rest-normalized values. In one study the mean absolute differences between baseline root mean square (RMS) values and maximum RMS values (MVC-normalized) were expressed as percentages of the maximum voluntary electrical activation, and in another study the area under the EMG activity curve during coughing was expressed in microvolt seconds.

Comparisons of pressure measurements and test activities

The various studies compared the pressures in different structures related to the PFMs, for example intrarectal, intravaginal,

Table 2: Summary of results concerning measurements methods, test position and activities, EMG activity, timing, comparison within pressure measurements or test activities and reliability of EMG data

Measurements methods	Test position	Test activity	EMG activity	Timing	Relationships PFMs to	Reliability
Vaginal probe	Supine	Coughing	Maximal EMG activity in %	EAS – EIC	Bladder pressure	ICC
Periform Femiscan	Crook lying	Running		EAS – bladder pressure	Intrarectal pressure	Intra-session reliability
Stimpon			Mean EMG activity in %			
DSE®	Semi lithotomy	Horse riding				
MAPLe	Hemi supine	Rapid arm movements	Maximal EMG activity in µVolt	EAS – intra-abdominal pressure	Intravesical pressure	Inter-session reliability
Surface EMG						
EAS	Sitting		Mean EMG activity in µVolt	PFMs – posterior vaginal wall pressure	Cough leek point pressure	
Perineum	Standing	Weight catching		EAS – OI, OE, RA and ES	Intensity of coughing	Motion artefact
Needle EMG	Treadmill		Area under the EMG average curve in µVolts	PFMs – heel strike	Coughing	
PFMs side						
Bulbo-cavernosus	Horse sitting				Recruitment of motor units	
Wire EMG			MAD in %MVE		Pelvis posture	
Pubo-coccyge-us					Sphincter of urethral wall	
					Wight loading	
					Running speed	
					Pace of horse riding	
					Bladder filling	

EMG electromyography, *MAD* mean absolute difference, *%MVE* percentage of maximum voluntary electrical activation, *PFMs* pelvic floor muscles, *EAS* external anal sphincter, *EIC* external intercostal muscle, *OE* obliquus externus, *OI* obliquus internus, *RA* rectus abdominis, *ES* erector spinae

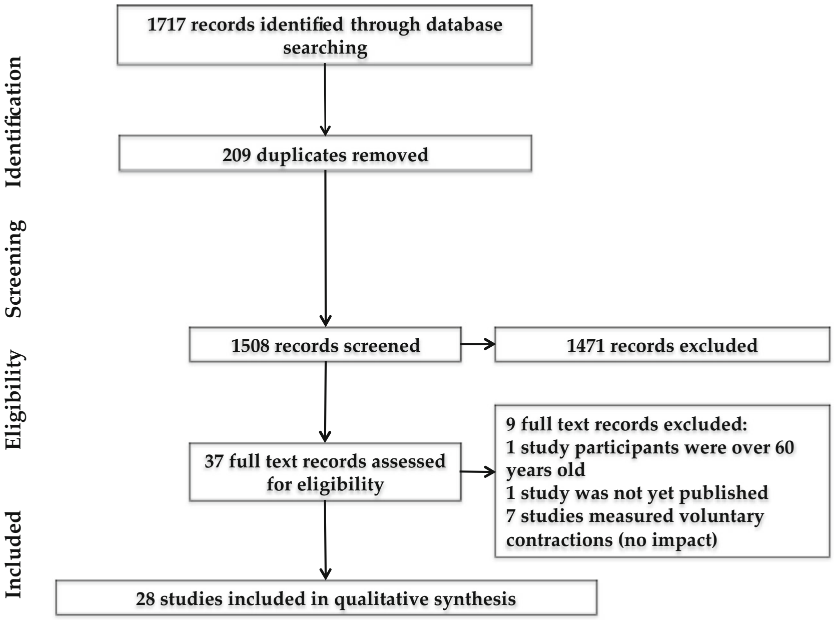

Fig. 1 Flow chart showing the study selection process

intraabdominal, bladder, posterior vaginal wall and cough leak point pressures. Other studies compared PFM activity and the activities of the abdominal, external intercostal, deltoid and striated urethral muscles. The relationship between bladder filling volume and PFM activity was also studied. Some studies also compared different activities, such as different places during horseback riding, angle of the pelvis, foot contact with the ground, running speed, weight loading, coughing, and coughing at different intensities.

Test positions and activities

Of the studies, a supine position was used in 16, including crook lying (flexion at the hip and knee joints), semilithotomy, and hemi-supine position, a standing position was used in 13 studies, and both supine and standing positions were used in 5 studies. Sitting in an armchair and sitting on horseback were each used in one study. In 20 studies the activity tested was coughing ranging from single to several coughs of different intensities. In three studies, the activity tested was running on a treadmill at different speeds. Other test activities included horseback riding, weight catching, and rapid arm movements.

PFM activity timing

A summary of the results on the timing of PFM activity is presented in Table 4. All studies that investigated PFM activity (11 studies) to determine the latency of onset of PFM activity in comparison with changes in other structures expressed the results in milliseconds [17, 19, 20, 22, 23, 26, 28, 29, 32, 35, 37]. Six studies compared women with and without SUI. Four studies investigated the EAS using self-adhesive surface electrodes, six studies used vaginal EMG and one investigated PFM activity using wire EMG. The starting positions used included supine, standing, sitting and semilithotomy. As well as coughing as the activity, two studies determined the onset of PFM activity during rapid arm movements [26, 35] and two during running [28, 29]. Four studies determined the median latency between the onset of EAS activity and the onset of external intercostal muscle activity during coughing [20, 22, 23, 37]. All studies showed that continent women contracted the EAS before the external intercostal muscle. The onset of PFM activity was not only compared with the onset of external intercostal muscle activity but also with the onset of trunk muscle activity, and was also investigated in relation to the increases in intraabdominal pressure, bladder pressure and posterior vaginal wall pressure peak, and the time of heel strike [17, 19, 20, 26, 32, 35].

Madill et al. [32] compared the timing of the PFM EMG peak and the posterior vaginal wall pressure peak in women in the standing and supine positions. The effect of continence status on the relative timing of the peak PFM EMG and of the posterior vaginal wall pressure increase was influenced by position. Capson et al. [19] investigated healthy women coughing in three different standing postures (normal lumbopelvic posture, hyperlordosis, and hypolordosis). Posture did not affect the activation time of any of the muscles under study. Smith et al. [34] found that the onset of PFM activity during rapid shoulder flexion and extension was different in continent and incontinent women (before and after anterior deltoid EMG activity, respectively). The onset of the PFM EMG activity did not change with the direction of shoulder movement ($p = 0.70$) or bladder fullness (all $p > 0.23$). PFM activity was lower in some women before the onset of the postural activity, which was a novel finding.

Table 3 Newcastle-Ottawa scale scores for cross-sectional studies

Reference	Newcastle-Ottawa scale scores (number of stars)		
	Selection[a]	Comparability[b]	Outcome[c]
[15]	2		3
[16]	2		3
[17]	1	2	3
[18]	1		1
[19]	2		3
[20]	1		2
[21]	2	2	2
[22]	1	2	3
[23]	1	1	3
[24]	2		2
[25]	2		3
[26]	2		3
[27]	1		3
[28]	2		3
[29]	2		3
[30]	2		3
[31]	2	1	3
[32]	2	1	3
[5]	2	1	3
[33]	2		2
[34]	2		3
[35]	2	2	3
[36]	2	2	3
[37]	2	1	3
[38]	3	1	3
[39]	2		2

[a] Maximum 5 stars

[b] Maximum 2 stars

[c] Maximum 3 stars

Two studies that included running as an impact activity used heel strike as the reference point for timing, and analysed ten steps [28, 29]. Leitner et al. [28] measured PFM activity in continent and incontinent women at running speeds of 7, 11 and 15 km/h. The difference in PFM activity between the two groups of women and the differences in activity among the three speed conditions were not statistically significant.

Relationships between PFM activity and pressure measurements and test activities

A summary of the relationships between PFM activity and pressure measurements and test activities is presented in Table 5. Fifteen studies investigated the relationships between PFM EMG activity and the pressure of intraabdominal structures, bladder filling volume, posture and different test activities [5, 15, 18, 19, 21, 23–25, 28, 33–36, 39, 40]. Seven studies compared women with and without SUI. Three studies evaluated EAS activity using self-adhesive surface electrodes, five studies used vaginal EMG, one study used self-adhesive surface electrodes on the perineum, and three studies evaluated the PFMs using wire EMG and three using needle EMG. The starting positions used were supine, standing, sitting on horseback and hemi-supine. In addition to coughing as the activity, other activities included rapid arm movements, running, load-catching tasks and horseback riding. Coughing was found to cause a significant increase in intrarectal and intravaginal pressures, bulbocavernosus muscle EMG activity [34], and PFM EMG activity [5] with synergistic contraction of the striated urethral wall muscle [18, 40]. EAS EMG activity was found to increase with the intensity of coughing [15]. PFM EMG activity increased during load-catching tasks [36], with increasing horseback riding speed [33] and with increasing speed of running [28]. Deindl et al. [24, 25] found tonic, phasic and intermediate motor unit activity patterns during relaxation and coughing. In continent women, the motor units were activated bilaterally, whereas in parous women with SUI activation of the motor units was dissociated during reflex activity [25].

Quantification of PFM activity

Eleven studies quantified PFM activity in different EMG units. Only two studies compared women with and without SUI and one study included only women with SUI. Two studies evaluated the EAS using self-adhesive surface electrodes and six studies using vaginal EMG, one study evaluated the PFMs using wire EMG, one study evaluated the bulbocavernosus muscle using needle EMG, and one study used self-adhesive surface electrodes on the perineum. The starting positions used were supine, standing, sitting on horseback, hemi-supine and semilithotomy. In addition to coughing as the activity, other activities included rapid arm movements, running and horseback riding. Luginbuehl et al. [31] determined MVC-normalized PFM EMG activities (mean %EMG) during coughing in 11 healthy women. They also investigated the time intervals (as discussed by Fleischmann et al. [41]) from preactivity (initial time of coughing minus 30 ms) to reflex activity (0–30 ms, 30–60 ms, 60–90 ms, 90–120 ms and 120–150 ms). Luginbuehl et al. [29] also investigated healthy women while running a sequence of ten steps at a velocity of 8 km/h. They expressed their data in MVC-normalized PFM EMG (%EMG). 50 ms before heel strike they measured preactivity and at heel strike reflex activity. The mean EMG activity between EMGmin and EMGmax was 68% higher than during standing at rest ($p = 0.796$).

Another study by Luginbuehl et al. [30] analysed three different running speeds (7, 9 and 11 km/h) in healthy women. They investigated the same time intervals (as discussed by

Table 4 Times between onset of PFMs/EAS activity and onset of trunk and arm muscle activities and increases in pressure for different impact activities

Reference	Study groups	Subject characteristics			Measurement methods	Test position	Test activity	Period measured	Time (ms)	
		No. of subjects	Age (years)	Parity					Continent	SUI
[17]	Continent SUI	Continent 28 SUI 32	Continent 43.92 (30–52) SUI 43.03 (27–52)	Continent 2 in 26, 1 in 2 SUI 1 in 31, 3 in 1 (vaginal deliveries)	Left and right levator ani muscle wire EMG, intravesical pressure measured using transducer catheter	Semilithotomy	Three coughs; 250 ml bladder filling volume	PFM activity onset − increase in bladder pressure	Left side: 25 (0 to 106), $p < 0.001$ Right side: 50 (0 to 126), $p < 0.001$	Left side: −147 (−300 to 0), $p < 0.001$ Right side: −150 (−360 to 0), $p < 0.001$
[19]	Continent	16	27.1 ± 5.48	0	Surface EMG Periform™ vaginal probe, bipolar electrodes for RA, OI, OE and ES	Standing	Maximum three coughs	PFM activity onset − RA activity onset PFM activity onset − RA peak activity PFM activity onset − ES peak activity PFM activity onset − OI and OE peak activity	−106 ± 33, $p = 0.003$ 292 ± 93, $p = 0.003$ 450 ± 91, $p = 0.003$ Simultaneous, $p = 0.003$	–
[23]	Continent with OAB SUI	Continent 6 SUI 20	Continent 48.8 ± 17.6 SUI 47.6 ± 13.5	Continent 1.6 ± 1.0 SUI 1.6 ± 1.0	Surface self-adhesive electrodes positioned laterally EAS and EIC	Supine	One voluntary cough, empty bladder	EAS activity onset − EIC activity onset	470 (612 to 173), $p = 0.012$	60 (102 to −43), $p = 0.012$
[22]	Continent SUI	Continent 10 SUI 10	Continent 26.8 ± 7.1 SUI 39.0 ± 7.6	Continent 0 SUI 2.0 (0.5 to 2.7)	Self-adhesive surface electrodes positioned laterally on EAS and EIC	Supine	Three coughs, empty bladder	EAS activity onset − EIC activity onset	210 (398 to 135), $p < 0.001$	0 (30 to −111.7), $p < 0.001$
[20]	Continent with OAB	15	53 (34–78)	–	Self-adhesive surface electrodes positioned laterally on EAS and EIC, catheter in rectum	Supine	Three coughs, empty bladder	EAS activity onset − EIC activity onset EAS activity onset − IAP increase	40 to 800 Mean 615 ± 278	–
[26]	Continent	6	45.6 (35–63)	0 in 1, others 2–4 deliveries in the others	Surface EMG Periform™ vaginal probe and self-adhesive surface electrodes positioned laterally on EAS, disc electrodes on the anterior and posterior deltoid muscle	Standing	One shoulder flexion or extension as fast as possible	PFM activity onset − anterior or posterior deltoid muscle activity onset EAS activity onset − anterior or posterior deltoid muscle activity onset	28.4 ± 30, $p = 0.62$ 15.1 ± 36, $p = 0.63$	–
[28]	Continent SUI	Continent 28 SUI 22	Continent 38.7 ± 10.0 SUI 45.3 ± 9.5	–	Surface EMG tripolar STIMPON™ vaginal probe	Treadmill	Running at 7, 11 and 15 km/h, empty bladder	Maximum PFM activity − heel strike	7 km/h −125.6 ± 65.2 11 km/h −116.6 ± 62.7 15 km/h −130.5 ± −65.7 $p > 0.05$	7 km/h −110.3 ± 58.1 11 km/h −109.7 ± 63.0 15 km/h −103.8 ± 48.2 $p > 0.05$
[29]	Continent	10	24.10 ± 2.77	–	Surface EMG Periform™ vaginal probe	Treadmill	Running at 8 km/h, empty bladder	Maximum PFM activity − heel strike Minimum PFM activity − heel strike	Mean −214.2 ± 51.8, $p = 0.517$ Mean 3.7 ± 57.2, $p = 0.604$	–

Table 4 (continued)

Reference	Study groups	Subject characteristics			Measurement methods	Test position	Test activity	Period measured	Time (ms)	
		No. of subjects	Age (years)	Parity					Continent	SUI
[32]	Continent Mild SUI Severe SUI	Continent 8 Mild SUI 8 Severe SUI 8	Continent 51.6 ± 6.2 Mild SUI 52.3 ± 7.0 Severe SUI 53.5 ± 6.0	Continent 1.9 ± 1.1 Mild SUI 2.4 ± 1.2 Severe SUI 2.4 ± 0.5	Surface EMG Femiscan™ vaginal probe, pressure transducers mounted on vaginal probe to measure PVW pressure	Supine and standing	Maximum three coughs	Maximum PFM activity − PVW pressure peak	Simultaneous, $p = 0.021$	Mild SUI: supine, simultaneous; standing, 183 ± 209 Severe SUI: supine, 408 ± 462; standing, 245 ± 321 $p = 0.021$
[35]	Continent SUI	Continent 14 SUI 16	Continent 52.5 ± 12.5 SUI 49.8 ± 12.0	Continent 2.4 ± 1.5 SUI 1.9 ± 1.1	Surface EMG Periform™ vaginal probe, disc electrodes anterior and posterior deltoid muscle	Standing	One shoulder flexion or extension as fast as possible, bladder empty or moderately full	PFM activity onset − anterior or posterior deltoid muscle activity onset	Main effect: Anterior deltoid muscle: 18.1 ± 33, $p < 0.05$ Posterior deltoid muscle: 26.9 ± 49, $p < 0.05$ Empty bladder: Anterior deltoid muscle: 15.1 ± 34, $p < 0.05$ Posterior deltoid muscle: 31.2 ± 35, $p < 0.05$ Full bladder: Anterior deltoid muscle: 21.6 ± 33, $p < 0.05$ Posterior deltoid muscle: 22.5 ± 61, $p < 0.05$	Main effect: Anterior deltoid muscle: −5.3 ± 36, $p < 0.05$ Posterior deltoid muscle: −15.45 ± 43, $p < 0.05$ Empty bladder: Anterior deltoid muscle: 4.8 ± 32, $p < 0.05$ Posterior deltoid muscle: 9.4 ± 43, $p < 0.05$ Full bladder: Anterior deltoid muscle: 5.8 ± 41, $p < 0.05$ Posterior deltoid muscle: 22.4 ± 44, $p < 0.05$
[37]	Continent	33	28 (23–29)	0 (0–0)	Self-adhesive surface electrodes positioned laterally on the EAS and EIC	Sitting in a chair with arm support	Ten coughs with and without DT	EAS activity onset − EIC activity onset	Without DT: 80 (107 to 56) With DT: 56.07 (94 to 2) $p = 0.005$	–

The data are presented as means ± standard deviation or medians (interquartile range); positive values indicate that the PFMs/EAS contracted before the other structure

SUI stress urinary incontinence, *OAB* overactive bladder syndrome, *EAS* external anal sphincter, *EIC* external intercostal muscle, *IAP* intraabdominal pressure, *PVW* posterior vaginal wall pressure, *ES* erector spinae, *RA* rectus abdominis, *OE* obliquus externus, *OI* obliquus internus, *PFM* pelvic floor muscle, *EMG* electromyography, *DT* distraction task

Table 5 Relationships between PFM activity and pressure measurements, bladder filling volume and test activities

Reference	Study groups	Subject characteristics			Measurement methods	Test position	Test activity	Relationship investigated	Results	
		No. of subjects	Age (years)	Parity					Continent	SUI
[15]	Continent with OAB	16	52 ± 12	–	Self-adhesive surface electrodes positioned laterally on the EAS and EIC	Supine	Four voluntary coughs (gentle, moderate, strong, very strong) with 0, 100, 200, 300 and 400 ml bladder filling volume	BP (intensity of coughing) and integrated EAS EMG activity	Gentle 108 ± 89 µV Moderate 165 ± 128 µV Strong 238 ± 167 µV Very strong 263 ± 223 µV	–
[40]	Continent SUI	Continent 11 SUI 11[a]	Continent 20.4 ± 2.3 SUI 19.9 ± 1.9	Nulliparous	Needle EMG in striated urethral wall muscle and PFMs	Supine	Cough	EMG activity of striated urethral wall muscle and PFMs	Synergistic contraction of striated urethral wall muscle and PFMs	Synergistic contraction of striated urethral wall muscle and PFMs
[18]	Continent	6	19.5 (19–21)	Nulliparous	Needle EMG in striated urethral wall muscle and PFMs	Supine	Cough	EMG activity of striated urethral wall muscle and PFMs	Synergistic contraction of striated urethral wall muscle and PFMs	–
[19]	Continent	16	27.1 ± 5.48	0	Surface EMG Periform™ vaginal probe, bipolar electrodes for RA, OI, OE and ES	Standing	Maximum three coughs and load catching tasks	PFM activity and posture	Significantly more PFM EMG activity standing in the habitual posture than in a hyperlordosis or a hypolordosis posture	–
[23]	Continent with OAB SUI	Continent 6 SUI 20	Continent 48.8 ± 17.6 SUI 47.6 ± 13.5	Continent 1.6 ± 1.0 SUI 1.6 ± 1.0	Self-adhesive surface electrodes positioned laterally on the EAS and EIC	Supine	Four coughs at 0, 200 and 400 ml bladder filling volume; four successive voluntary coughs of increasing intensity (gentle, moderate, strong, very strong)	Normalized EAS EMG activity and bladder filling volume	Bladder filling volume did not significantly affect EAS EMG, $p = 0.12$	Bladder filling volume did not significantly affect EAS EMG, $p = 0.12$
[21]	Continent with OAB SUI Mixed incontinence	Continent 4 SUI 6 Mixed incontinence 11	Continent 39 (24–53) SUI 47.6 ± 13.5		Self-adhesive surface electrodes positioned laterally on the EAS and EIC	Supine	Four coughs at 0, 200 and 400 ml bladder filling volume; four successive voluntary coughs of increasing intensity (gentle, moderate, strong, very strong)	Normalized EAS EMG activity and BP bladder filling volume	Bladder filling volume did not significantly affect the relationship between EAS and BP, $p = 0.10$	EAS EMG activity for a given BP was lower in SUI than in continent subjects, except 400 ml bladder filling volume for which it was the opposite, $p = 0.027$ The relationship between EAS EMG activity and BP was significantly different between continent and SUI groups, $p = 0.0001$ (likelihood ratio test)

Table 5 (continued)

Reference	Study groups	Subject characteristics			Measurement methods	Test position	Test activity	Relationship investigated	Results	
		No. of subjects	Age (years)	Parity					Continent	SUI
[24]	Continent	10 (9 measured)	27.2 (22–23)	Nulliparous	Wire electrodes, percutaneous into left and right pubococcygeal muscle	Supine and standing, bladder full	Single coughs and continuous coughing for 5 s	Coughing and motor unit recruitment	Concomitant recruitment of motor units observed in both pubococcygeal muscles; coughing elicited recruitment of motor units	–
[25]	Continent SUI	Continent 10 (9 measured) SUI 8 (5 measured)	Continent 27.2 (22–23) SUI 45.3 (31–60)	Continent nulliparous SUI 2.75 (2–4)	Wire electrodes, percutaneous into left and right pubococcygeal muscle	Supine and standing, bladder full	Single coughs and continuous coughing for 5 s	Coughing and motor unit recruitment	Concomitant recruitment of motor units observed in both pubococcygeal muscles; coughing elicited recruitment of motor units	One subject with SUI showed normal activation during MVC; during coughing absence of symmetrical activation (left side no activation; unilateral reflex coordination disturbance) Three of four parous women showed expected activation of motor unit only on one side (contralateral side paradoxical inhibition)
[28]	Continent SUI	Continent 28 SUI 22	Continent 38.7 ± 10.0 SUI 45.3 ± 9.5	–	Surface EMG tripolar STIMPON™ vaginal probe	Treadmill	Running at 7, 11 and 15 km/h, empty bladder	Maximal MVC-normalized EMG% and running speed	7 km/h: 98.6 ± 44.4%EMGmax 11 km/h: 143.0 ± 64.9%EMGmax 15 km/h: 200.0 ± 106.9%EMGmax $p < 0.05$	7 km/h: 45.3 ± 113.7%EMGmax 11 km/h: 174.8 ± 131.2%EMGmax 15 km/h: 238.7 ± 150.6%EMGmax $p < 0.05$
[5]	Continent	10	24 (18–36)	–	Wire electrodes percutaneous into left and right pubococcygeal muscle	Supine	Cough	Coughing and motor unit recruitment	PFM activity increased during coughing in seven of nine women; one women unable to contract voluntarily, but during coughing PFMs contracted	–
[33]	Healthy riders	Continent 13 SUI 1	22–48	Nulliparous 6, parous 8	Surface EMG VMS-3 vaginal probe	Sitting on horseback	Standardized horseback riding programme: walk, trot, gallop sitting, rising, half-sitting	PFM activity and riding intensity	Walk sitting: 5–12 μV Trot rising: 16–29 μV Gallop half-sitting: 26–42 μV Trot sitting: 16–30 μV Gallop sitting: 23–28 μV	–

Table 5 (continued)

Reference	Study groups	Subject characteristics			Measurement methods	Test position	Test activity	Relationship investigated	Results	
		No. of subjects	Age (years)	Parity					Continent	SUI
[34]	Continent	19	46.2 ± 10.4	Nulliparous 10, multiparous 9	Needle EMG in bulbocavernosus muscle left and right side	Supine	Sudden coughing	Bulbocavernosus muscle activity and intrarectal and intravaginal pressure	Coughing significantly increased intrarectal and intravaginal pressure ($p < 0.001$), and bulbocavernosus muscle EMG activity	–
[36]	Continent SUI	Continent 14 SUI 16 (mild ≤3/12, severe ≥4/12 SUI)	Continent 52.5 ± 12.5 SUI 49.8 ± 12.0 $p = 0.54$	Continent 2.4 ± 1.5 SUI 1.9 ± 1.1 $p = 0.40$	Periform Intravaginal probe	Standing	1-kg weight dropped from 30 cm at expected and unexpected times with bladder empty or moderately full	PFM activity and load-catching task; effect of bladder filling volume on normalized PFM activity	PFM EMG activity increased during load-catching task; there was a similar trend with expected and unexpected loading; all women had greater PFM EMG ($p < 0.001$) when loading was unexpected. PFM EMG activity was lower with bladder moderately full than empty ($p = 0.007$)	Incontinent women showed greater raw PFM EMG activity and greater raw obliquus externus EMG activity ($p = 0.058$) during load catching ($p = 0.034$) than control women; PFM EMG activity was lower with bladder moderately full than empty ($p = 0.007$)
[35]	Continent SUI	Continent 14 SUI 16 (mild ≤3/12, severe ≥4/12 SUI)	Continent 52.5 ± 12.5 SUI 49.8 ± 12.0 $p = 0.54$	Continent 2.4 ± 1.5 SUI: 1.9 ± 1.1 $p = 0.40$	Periform intravaginal probe	Standing	One shoulder flexion or extension as fast as possible; bladder empty or moderately full	Effect of bladder filling volume on onset of PFM activity; effect of bladder filling volume on normalized PFM activity	Bladder filling volume did not significantly affect the onset of PFM EMG activity ($p > 0.23$); PFM EMG activity was lower with bladder moderately full than empty ($p = 0.012$)	Bladder filling volume did not significantly affect the onset of PFM EMG activity ($p > 0.23$); PFM EMG activity was lower with bladder moderately full than empty ($p = 0.012$)
[39]	SUI: Group 1: VLPP <60 hPa Group 2: VLPP 61–90 hPa Group 3: VLPP >90 hPa	54	48 ± 16	Multiparous 78%	Surface electrodes on perineum	Hemi-supine	Coughing with 300 ml bladder filling volume	Mean EMG in microvolts at CLPP and VLPP	–	PFM EMG activity was significantly higher at CLPP than at VLPP ($p < 0.01$) CLPP: group 1, 28 ± 12 µV; group 2, 9 ± 14 µV; group 3, 36 ± 5.9 µV VLPP: group 1, 10 ± 5.6 µV; group 2, 12 ± 5.8 µV; group 3, 17 ± 8.2 µV

The data are presented as means ± standard deviation

SUI stress urinary incontinence, *OAB* overactive bladder syndrome, *EAS* external anal sphincter, *EIC* external intercostal muscle, *BP* bladder pressure, *PFMs* pelvic floor muscles, *EMG* electromyography, *VLPP* Valsalva leak-point pressure, *CLPP* cough leak-point pressure, *MVC* maximum voluntary contractions

[a] Urodynamic assessment in 14 subjects

Fleischmann et al. [41]) as previously investigated in the coughing study to analyse the data and also express reflex activity in relation to the time intervals. The highest activity at all three running speeds was found during the time interval 30–60 ms. In the third running study [28], preactivity and reflex activity increased significantly with speed. The authors used the same time intervals as used by Fleischmann et al. [41] and mean %EMG (MVC-normalized). Mean %EMG activity while running was significantly higher than the PFM activity at onset. At a speed of 15 km/h, the values exceeded 100%EMG for all time intervals in all women with SUI. The highest activity at all three running speeds in both groups was during the time interval −30 to 0 ms (preactivity), except in women with SUI running at 15 km/h during the interval 0–30 ms. The highest reflex activity was found during the interval 0–30 ms. There were no statistically significant differences in %EMG values between the two groups for any of the time intervals.

Auchincloss and McLean [16] used two different vaginal probes to test 12 healthy nulliparous women. They calculated the mean absolute difference (baseline RMS values subtracted from maximum RMS values, and MVC-normalized) as a percentage of maximum voluntary electrical activation. Barbic et al. [17] evaluated the activation of the levator ani muscle during coughing using the area under the EMG activity curve. They measured the left and right sides separately. A summary of these results is presented in Table 6.

Discussion

Main findings

Studies used a wide range of PFM EMG measurement methods, including vaginal probe, surface, needle and wire EMG, with a wide array of EMG calculations. Several reflex tasks were compared, including coughing, running, rapid arm movements, load catching and horseback riding, in different test positions. The times in relation to the onset of activity of other trunk muscles were found to be important. During impact activities, PFMs contracted before other trunk and arm muscles in continent women, but in incontinent women PFMs contracted later [22, 23, 26, 35]. This was observed during coughing [22, 23] and rapid arm movements [26, 35]. The time from the onset of PFM activity to the onset of intraabdominal, urethral and posterior vaginal wall pressure increases was also found to be important [17, 32]. During coughing, the PFMs activate and increase urethral pressure before the increase in intraabdominal pressure to guarantee continence [17, 20, 21]. In women with moderate to severe SUI, PFM EMG activity peaks before the posterior vaginal wall pressure, whereas in continent women PFM EMG activity and posterior vaginal wall pressure peak at the same time [32].

Coughing significantly increases bladder, intrarectal and intravaginal pressure and PFM EMG activity [4, 15, 18, 34, 40]. PFM EMG activity increases with the intensity of coughing [15]. PFM reflex activity during coughing is not a direct response, but is a modulated reflex that gradually adapts to the impact task [15]. This gradual adaptation was also evident at different running and horseback riding speeds [15, 33]. The findings of Luginbuehl et al. and Leitner et al. show that PFM preactivity occurs during running, ranging from 72.1 to 136.9%EMG of MVCmax [28, 30]. This aspect of PFM function was also seen during coughing, with mean preactivity values of 35.1 ± 14.0%EMG [31]. Like other muscles, the PFMs can activate to a higher level than MVC activity during impact activities. Leitner et al. found PFM activity up to 200%EMG in incontinent women during running [28]. Coughing appears to activate the PFM to a level between 35.1 and 71.2%EMG in relation to MVCmax [31]. PFM EMG activation was significantly higher at cough leak-point pressure than at Valsalva leak-point pressure [39].

During impact activities incontinent women had higher PFM activity than continent women [28, 35, 36]. In contrast, Deffieux et al. [21] found that during coughing normalized EAS EMG activity for a given bladder pressure value is lower in women with SUI than in continent women, except for a bladder filling volume of 400 ml for which the opposite was the case ($p = 0.027$). In PFMs slow twitch muscle fibres maintain basal tonus, while fast twitch muscle fibres are recruited for rapid contractions [24]. Deindl et al. [24, 25] found that parous women with SUI have asymmetrical and uncoordinated levator ani muscle activation patterns, which suggests the presence of behavioural abnormalities. Posture was found to have no influence on timing, but in a neutral pelvis position PFM activity is higher than in hypolordosis or hyperlordosis postures [19]. Three studies showed that bladder filling does not affect PFM activity [15, 21, 23], but two showed that PFM activity decreases and abdominal and erector spinae EMG activity increases when the bladder is moderately full [35, 36].

In the study by Voorham-van der Zalm et al. [38], the vaginal probe (MAPLe) was misplaced during an MRI study of women coughing, and so they did not analyse coughing data. Keshwani et al. [27] investigated motion artefact for two different vaginal probes by analysing the power spectrum of the raw EMG data recorded during coughing, and found that 14.4–29.3% of the files were affected by motion artefacts.

Strengths and limitations: significance and implications, limits of current knowledge

The multidisciplinary authorship with the inclusion of urogynaecologists, physiotherapists, and sports and physical education scientists among the authors can be viewed as a strength of this review. However, there are several limitations of this review. First, most of the included studies had an

Table 6 PFM activity values for different impact activities

Reference	Study groups	Subject characteristics			Measurement methods	Test position	Test activity	EMG units	PFM activity	
		No. of subjects	Age (years)	Parity					Continent	SUI
[15]	Continent with OAB	16	52 ± 12	–	Self-adhesive surface electrodes positioned laterally on the EAS and EIC	Supine	Four voluntary coughs (gentle, moderate, strong, very strong) with 0, 100, 200, 300 and 400 ml bladder filling volume	Mean EMG (microvolts)	Gentle 108 ± 89 μV Moderate 165 ± 128 μV Strong 238 ± 167 μV Very strong 263 ± 223 μV	–
[16]	Continent	10	30 ± 3.9	Nulliparous	Surface EMG Periform™ and Femiscan™ vaginal probe	Supine and standing	Standardized coughing	Mean absolute difference (MVC-normalized) expressed as (%MVE)	Supine: 22.66 ± 15.34%MVE; 84.16 ± 92.69%MVE Standing: 28.87 ± 20.39%MVE; 89.81 ± 169.52%MVE	–
[17]	Continent SUI	Continent 28 SUI 32	43.92 (30–52) SUI: 43.03 (27–52)	Continent, 2 in 26 and 1 in 2 SUI, 1 in 31 and 3 in 1 (vaginal deliveries)	Left and right levator ani muscle wire EMG, intravesical pressure measured by transducer catheter	Semilithotomy	Three coughs; 250 ml bladder filling volume	Area under the EMG activity curve (microvolt seconds)	Left side: 239 μVs (122 to 348 μVs) Right side: 291 μVs (141 to 697 μVs) $p < 0.591$	Left side: 385 μVs (181 to 609 μVs) Right side: 260 μVs (143 to 511 μVs) $p < 0.046$
[20]	Continent with OAB	3	25–29	Nulliparous	Self-adhesive surface electrodes positioned laterally on the EAS	Supine	Three coughs; empty bladder	Mean EMG (microvolts) Rest-normalized %EMG	10.1, 53.8, 101.2 μV 228, 659, 906%	–
[28]	Continent SUI	Continent 28 SUI 22	Continent 38.7 ± 10.0 SUI 45.3 ± 9.5	–	Surface EMG tripolar STIMPON™ vaginal probe	Treadmill	Running at 7, 11 and 15 km/h, empty bladder	Mean MVC-normalized %EMG, preactivity and reflex activity, maximum EMG	Preactivity: 7 km/h: 63.2 ± 30.5 11 km/h: 91.2 ± 56.2 15 km/h: 118.6 ± 74.0 Reflex activity: 7 km/h: 56.1 ± 24.2 11 km/h: 86.8 ± 39.0 15 km/h: 118.6 ± 79.0 EMGmax: 7 km/h: 98.6 ± 44.4 11 km/h: 143.0 ± 64.9 15 km/h: 200.0 ± 106.9 $p < 0.05$	Preactivity: 7 km/h: 92.0 ± 77.3 11 km/h: 107.5 ± 77.9 15 km/h: 136.9 ± 89.8 Reflex activity: 7 km/h: 84.4 ± 64.6 11 km/h: 103.3 ± 62.6 15 km/h: 151.8 ± 102.1 EMGmax: 7 km/h: 145.3 ± 113.7 11 km/h: 174.8 ± 131.2 15 km/h: 238.7 ± 150.6 $p < 0.05$
[30]	Continent	10	20–35	Nulliparous	Surface EMG Periform™ vaginal probe	Treadmill	Running at 7, 9 and 11 km/h, empty bladder	Mean MVC-normalized %EMG, preactivity and reflex activity	Preactivity: 7 km/h: 76.1 ± 4.3%, $p = 0.097$	–

Table 6 (continued)

Reference	Study groups	Subject characteristics			Measurement methods	Test position	Test activity	EMG units	PFM activity	
		No. of subjects	Age (years)	Parity					Continent	SUI
									9 km/h: 75.14 ± 2.8%, $p = 0.709$ 11 km/h: 91.6 ± 5.5%, $p = 0.052$ Reflex activity: 7 km/h: 88.4 ± 5.2%, $p = 0.115$ 9 km/h: 84.9 ± 8.3%, $p = 0.091$ 11 km/h: 106.1 ± 10.8%, p = 0.359	
[31]	Continent	11	23.8 ± 2.3	–	Surface EMG Periform™ vaginal probe	Standing	Three standardized coughs	Mean MVC-normalized %EMG, preactivity and reflex activity	35.1–52.2%. $p < 0.05$ Preactivity values: 35.1 ± 14.0 Maximum reflex activity: 52.2 ± 19.8	–
[29]	Continent	10	24.10 ± 2.77	–	Surface EMG Periform™ vaginal probe	Treadmill	Running at 8 km/h; empty bladder	Mean MVC-normalized %EMG, preactivity and reflex activity	Preactivity 72.1 ± 40.1%, $p = 0.064$ At heel strike 64.0 ± 27.0%, $p = 0.164$ Minimum EMG: 55 ± 24.9%, $p = 0.311$ Maximum EMG: 124.3 ± 99.2%, $p = 0.848$ Mean EMG: 99.2 ± 81.6%, $p = 0.796$	–
[33]	Healthy riders	Continent 13 SUI 1	22–48	Nulliparous 6, parous 8	Surface EMG VMS-3 vaginal probe	Sitting on horseback	Standardized horseback riding programme: walk, trot, gallop sitting, rising, half-sitting	Mean EMG activity (microvolts)	Walk sitting 5–12 µV Trot rising 16–29 µV Gallop half-sitting: 26–42 µV Trot sitting:16–30 µV Gallop sitting: 23–28 µV 3.4 mean reference value (standing still) Walk sitting: 5–12 µV Trot rising: 16–29 µV Gallop half-sitting: 26–42 µV Trot sitting: 16–30 µV Gallop sitting: 23–28 µV	–
[34]	Continent	19	46.2 ± 10.4	Nulliparous 10, multiparous 9	Needle EMG in bulbocavernosus	Supine	Sudden coughing	Mean EMG (microvolts)	408 ± 30.4, range 386–489, $p < 0.01$	–

Table 6 (continued)

Reference	Study groups	Subject characteristics			Measurement methods	Test position	Test activity	EMG units	PFM activity	
		No. of subjects	Age (years)	Parity					Continent	SUI
					muscle left and right side					
[39]	SUI: Group 1: VLPP <60 hPa Group 2: VLPP 61–90 hPa Group 3: VLPP >90 hPa				Surface electrodes on the perineum	Hemi-supine	Coughing with 300 ml bladder filling volume	Mean EMG (microvolts) at CLPP		Group 1: 28 ± 12 μV Group 2: 29 ± 14 μV Group 3: 36 ± 5.9 μV $p < 0.01$

The data are presented as means ± standard deviation or medians (interquartile range)

SUI stress urinary incontinence, *OAB* overactive bladder syndrome, *EAS* external anal sphincter, *EIC* external intercostal muscle, *EMG* electromyography, *VLPP* Valsalva leak-point pressure, *CLPP* cough leak-point pressure, *%MVE* percentage of maximum voluntary electrical activation, *MVC* maximum voluntary contractions

observational design (cross-sectional studies), in which there is a moderate risk of bias. Furthermore, the study findings were heterogeneous. Another problem could have been the EMG measurements themselves. EMG evaluates the state of the muscle by recording the electrical activity of the peripheral neuromuscular system. EMG can involve the use of either intramuscular electrodes (wire or needle) or surface electrodes (vaginal probes or electrodes placed on the skin). Therefore, EMG does not directly measure muscle strength, which means it is difficult to validate EMG as a measurement tool, in view of the fact that the gold standard of PFM evaluation is based on muscle strength [42]. This difficulty in validating the use of EMG for measuring PFM activity increases the risk of bias in the studies reviewed.

Intramuscular EMG (wire and needle) is considered more specific than surface EMG [43]. The problem is that wire or needle EMG reflects the muscle fibre activity at a specific location and may miss activation in other parts of the muscle [24, 25]. The use of vaginal probes during impact activities in controversial because the large surface area of the electrodes may result in crosstalk from adjacent muscles [44]. Additionally, in two studies included in this review, surface EMG motion artefacts were mentioned [27, 38]. However, Luginbuehl et al. found good intrasession test–retest reliability of surface EMG in healthy women during running [29].

Presentation of EMG data demonstrates another problem. Some of the studies included in this review interpreted non-normalized PFM EMG data quantitatively [15, 33, 34]. Non-normalized data must be treated with caution because muscle activity needs to be normalized to a reference contraction to reduce interindividual variability [45]. Care must be used in quantitative interpretation of PFM EMG data because of low intersession reliability and moderate to good intrasession reliability [16, 27, 29–31]. Burden et al. even recommended that normalized EMG data should not be compared among different trials, muscles and individuals [45]. Several studies included in this review did compare normalized EMG among different trials [16, 28–31]. Timing data are not affected by the problem associated with PFM EMG measurements.

Interpretation: significance and implications

Urinary continence is the result of a complex interaction among several structures, including PFMs, trunk muscles, organs, nerves and tendons. Multiple factors influence the evaluation of urinary continence, including the task, the diagnostic instrument, the test position, continence status, age, muscle condition, and fascial structures. This systematic review specificallyexplored PFM activity during impact activities and found a broad range of timings (latency of onset) of PFM activities to other muscles or pressure measurements, various test activities, and wide variability in quantification of the observed activities. These findings support the view that PFMs are not isolated structures, but must be seen in relation to connected structures when the timing and quantification of PFM activity are measured. Madill and McLean [46] found that the initial phase of increased intravaginal pressure during abdominal contraction is caused by PFM contraction. This finding supports the "subvesicular hammock" theory of Delancey [7]: abdominal pressure is transmitted to the urethra through a laterally subvesicular attachment to the arcus tendineus fascia pelvis and the PFMs. This endopelvic fascia tissue structure stiffens during reflex contraction of the PFMs and forms a supportive layer against which the urethra is compressed. DeLancey et al. subsequently found that maximal urethral closure pressure, and not urethral support, is the primary factor most strongly associated with continence [9]. Barbic et al. [17] agree that suburethral support is important and that the subvesicular hammock theory may be valid. Barbic et al. suggest that the time between the onset of PFM activity and the onset of abdominal pressure rise is important for continence. Deffieux et al. [47] confirmed this suggestion in a literature review, concluding that dysfunctional preactivation of the PFM reflex response contributes to the physiopathology of SUI. The importance of PFM activation timing during impact activities seems to be confirmed; specifically, PFM activation in women with SUI was shown to be delayed.

Deffieux et al. postulated that defective modulation of the PFM reflex response during coughing and delayed PFM activation in women with SUI are a pathophysiological mechanism in SUI, and described SUI as a multifactorial condition. They concluded that the central nervous system adapts the intensity and activation of the PFM response to the intensity of voluntary coughing [47]. The studies included in this review showed graded PFM activation during coughing, horseback riding, and running [15, 28, 30, 33]. Amarenco et al. [15] found an alteration in the modulation of the cough anal reflex, showing no gradation in the PFM response during different intensities of coughing in women with SUI. The gradual adaptation of PFMs is probably one of the main factors that contributes to continence in women [15]. During running, maximal PFM activity varied from 98.6 to 238.7%EMG, and preactivity from 72.1 to 136.9%EMG in relation to MVCmax [28, 30]. Impact activities such as running should be investigated in future research on PFM rehabilitation [48].

Three studies demonstrated that incontinent women have higher PFM activity than continent women during impact activities [28, 35, 36]. This finding challenges the clinical assumption that incontinence is associated with reduced PFM activity and suggests that although women with incontinence may have reduced muscle mass and maximal ability, the activity of their PFMs is greater during postural perturbation. These findings support the view that incontinence is caused by more than morphological changes in PFMs, and suggest that it may be due to altered muscle activation patterns [24] or to partial denervation of the PFMs [49]. The behavioural abnormalities in muscle activation patterns found in women with SUI may be due to unilateral injury (avulsion) that can happen during birth and affect PFM morphometry and function [49], and is relevant to treatment [24, 25]. PFM activity is highest with the pelvis in a neutral position, suggesting that posture should be considered in rehabilitation [19]. There are opposing findings concerning the influence of bladder filling volume on the PFM response [15, 21, 23, 35, 36], showing the complexity of the physiological linkage between bladder filling volume and PFM and abdominal muscle activity.

Conclusions: constraints of limitations, significance of findings and future research

The findings of this systematic review may help guide clinical studies seeking to determine best practices, for example in relation to integrating impact activities, especially running (view steps) with exercise, and to the activation of preactivity and reflex activity of the PFMs, since running is associated with intense involuntary PFM activation. However, we still do not clearly understand the pathomechanism of PFM activation during impact activities. Future research should focus on dynamic PFM activities due to the fact that continence is an involuntary reflex event.

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Compliance with ethical standards

Conflicts of interest None.

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