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Activation of the Striated Urethral Sphincter to Maintain Continence During Dynamic Tasks in Healthy Men

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Aims: Function of the striated urethral sphincter (SUS) in men is debated. Current evidence is limited to electromyographic (EMG) recordings made with concentric needle electrodes in supine. Understanding of SUS function requires investigation of SUS EMG activity using new recording techniques in dynamic tasks. The aim of this study was to evaluate timing and amplitude of SUS EMG at rest and during dynamic tasks that challenge continence by increasing intra-abdominal pressure (IAP). **Methods:** Investigative study of five healthy men aged 25–39 years. Measurements included SUS, anal sphincter (AS), and transversus abdominus (TrA) EMG, and IAP (recorded with a nasogastric pressure catheter). Participants performed four tasks that challenged postural control in standing (single and repetitive arm movement, stepping and load catching). **Results:** IAP amplitude and SUS activity were linearly correlated during repetitive arm movement (R^2: 0.67–0.88). During stepping SUS EMG onset preceded the IAP increase, but followed it with rapid arm movements. When the trunk was loaded unpredictably onset of SUS generally followed the increase in IAP. The modest sample size meant only younger men were tested. Future studies might investigate healthy older men or those with certain pathologies. **Conclusions:** Data show that SUS activity increases proportionally with IAP. This provided evidence that SUS contributes to continence when IAP is increased, and that postural control of the trunk involves activation of this muscle. *Neurourol. Urodynam. 31:36–43, 2012.* © 2011 Wiley Periodicals, Inc.

Key words: activity; continence; electrode; electromyography; function; male; sphincter; urinary incontinence

INTRODUCTION

There are two opposing views of striated urethral sphincter (SUS) function in men. Some propose SUS provides tonic resting urethral pressure with little change when continence is challenged.[1,2] Others suggest SUS responds to rapid increases in intra-abdominal pressure (IAP) (i.e., bladder pressure) with activity modulation relative to mechanical demand.[3,4] Both views are based on anatomical findings. Reports of primarily slow-twitch muscle fibers underpin the hypothesis of tonic activation,[1,2] whereas, evidence of fast-twitch fibers suggests potential for rapid activation.[3,4] Resolution of this debate has been hampered by limitations in electromyographic (EMG) recording techniques: needle recordings are limited to supine and transurethral surface electrodes are deemed inappropriate due to low amplitude[5] and variability from electrode movement. New recording techniques and controlled tasks are required to resolve the debate.

Challenges to posture are accompanied by increased IAP from abdominal muscle activation to maintain posture and increase spinal stiffness.[6] Continence mechanisms respond to prevent urine loss and enable IAP increase by stabilizing the floor of the abdominal cavity. If SUS is involved in dynamic control of continence its activity should transiently increase during such tasks.

If SUS activity increases during postural challenges a second question arises; does SUS react to increased IAP or is it preplanned? There is evidence for both possibilities for the anal sphincter (AS).[7,8] This study investigated SUS EMG during dynamic postural tasks, and determined whether activity changes precede or follow IAP increases. We hypothesized SUS activity would increase during dynamic tasks that increase IAP, and motor control theory lead us to predict this would precede IAP increases for volitional movements,[9] but not for unexpected perturbations.[10]

MATERIALS AND METHODS

Participants

Five healthy men (25–39 years, mean: 34.8) volunteered. Participants were excluded if they had any history of urinary tract disorders, major neurological disorders or adverse reactions to local anesthetics. Participants provided informed written consent and the Institutional Medical Research Ethics Committee approved the study. Participants were also involved in another experiment.[11]

EMG and IAP Recordings

Previous work has shown that high-quality SUS surface EMG recordings are possible with optimal electrode to muscle fiber orientation and a method to stabilize the electrode.[11] The current study used a disposable transurethral catheter electrode (size 6 Fr) (Fig. 1A)[11] to record SUS EMG and a rectal electrode (Neen, Oldham UK) to record AS EMG. Fine-wire

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electrodes (75 μm diameter, A-M Systems, Inc., Sequim, WA) were inserted into transversus abdominis (TrA) with ultrasound guidance.[12] Surface EMG electrodes (Noraxon, Inc., Scottsdale, AZ) were placed over the dominant anterior and posterior deltoid. A reference electrode (3M Ltd, St. Paul, MN) was placed over the iliac crest.

Participants self-inserted the catheter and rectal electrodes using aseptic techniques. Lignocaine 2% gel (20 ml, Pfizer Pty Ltd, Bentley, Australia) was administered before catheterization to reduce sensation upon insertion. The catheter was inserted until urine loss was observed (catheter tip in bladder). Electrodes were connected to the amplifier and participants gently contracted while withdrawing the catheter. Electrode placement adjacent to the SUS was confirmed when action potentials were recorded during voluntary contractions.[11] Electrode position was stabilized by suctioning the catheter to the mucosa via the urine port using a spring-fitted syringe.[11,13] A nasogastric pressure transducer (Gaeltec Ltd, Dunvegan, UK) recorded IAP (sampling rate: 500 Hz).

EMG was bandpass filtered (10–2,000 Hz; notch filter—50 Hz), amplified 2,000 times, and sampled at 10 kHz for SUS and TrA, and 4 kHz for deltoid and AS (Digitimer Ltd, Welwyn Garden City, UK). Samples were digitized using a Power 1401 data acquisition system and Spike2 software (Cambridge Electronic Design, Cambridge, UK).

Procedure

Muscle activity and IAP were investigated during postural disturbances in standing (Fig. 1B–E):

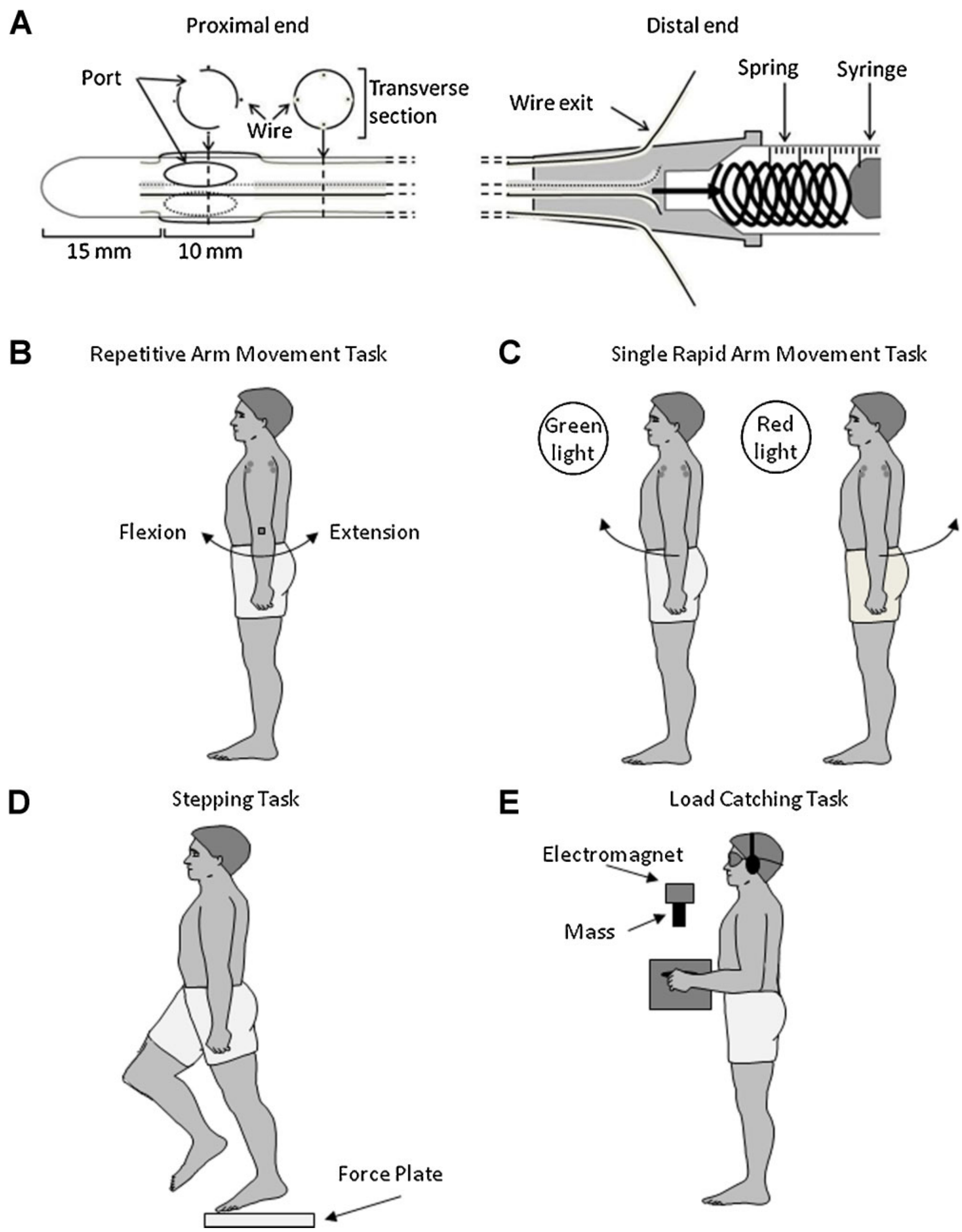

Fig. 1. Methods. **A**: Custom designed catheter electromyography (EMG) electrode to record from striated urethral sphincter in men. **B**–**E**: Tasks used to challenge posture and induce an increase in intra-abdominal pressure.

Voluntary/Predictable Tasks

(i) Repetitive arm movements—movement of the dominant arm between 15° flexion and extension at 1 Hz, guided by a metronome and then increasing velocity to maximum over ~10 sec. Glottis was closed and the task repeated three times. An accelerometer (Crossbow, Inc., Milpitas, CA) at the elbow recorded arm kinematics.
(ii) Single arm movements—flexion or extension of the dominant arm at the shoulder (as fast as possible) in response to a green or red light at eye level for 10 repetitions in random order.
(iii) Stepping—with the right foot on a force platform (Kistler, Winterthur, Switzerland) and left at equal height, a light prompted a rapid step forward with the right foot.

Unpredictable Task

(iv) Load catching—blindfolded participants held a bucket with 90° elbow flexion. A 1 kg mass, suspended 30 cm above the bucket by an electromagnet was dropped into the bucket to perturb the subject 10 times at unpredictable intervals.

All participants performed the tasks in the same order, were allowed time to rest for 5–20 min between tasks, and the opportunity to void if required with the electrode in situ. Previous work has shown that suction of the electrode to the mucosa ensures maintenance of consistent electrode placement over a period of 1.5 hr.[11]

Data Analysis

Matlab was used for analysis (The Mathworks, Inc., Natick, MA). For repetitive arm movement data, times of peak acceleration in each direction were identified. Peak acceleration, and root-mean-squared (RMS) EMG and mean IAP between 50 msec before to 50 msec after peak acceleration were calculated. Values were normalized to maximum across the task. SUS EMG and IAP were cross-correlated to identify latency between modulation of these variables.

Onsets of EMG and IAP (first deviation from baseline) were detected visually for single arm movements.[14] RMS EMG was calculated during 10-msec epochs between 100 msec before to 300 msec after deltoid EMG onset and normalized to the peak across the trial. Peak IAP above baseline was calculated.

For stepping trials, EMG and IAP onsets were detected visually. RMS EMG amplitude was calculated during 10-msec epochs from 200 msec before to 200 msec after the increase in vertical force (Fz) under the stepping foot (onset of the postural preparation[15]) and normalized to the peak across trials. IAP increase was calculated.

For the loading task EMG and IAP amplitude were calculated during 10-msec epochs between 100 msec before to 300 msec after loading. EMG onsets were difficult to identify in individual trials due to variability. Peak IAP increase was calculated.

Statistical Analyses

A linear regression using Pearson's r-squared correlation quantified the relationship between SUS EMG and peak arm acceleration for the repetitive arm movement. In the single arm movements, stepping and loading tasks EMG and IAP amplitudes were compared between epochs using repeated measures analyses of variance (ANOVA). IAP increase was compared between tasks using a repeated measures ANOVA. Post hoc testing used Duncan's multiple range test.

RESULTS

Repetitive Arm Movements

When subjects stood at rest prior postural tasks no tonic SUS EMG action potentials were identified. During repetitive arm movement, the peak arm acceleration linearly correlated with SUS RMS EMG (Fig. 2A). Correlation coefficients ranged from 0.74 to 0.88 (flexion) and 0.67 to 0.87 (extension). Relationships between IAP and SUS EMG (Fig. 2B), and between arm acceleration and other muscle EMG (Table I) were similar. Cross-correlation identified SUS EMG preceded IAP by 15.8 (5.4) msec.

Single Arm Movements

During rapid arm movements SUS EMG increased after the IAP increase, whereas AS and TrA EMG increased before IAP (Table II, Fig. 3). TrA and SUS epoch data provided consistent findings. Epoch analysis of AS EMG prior to IAP failed to reach significance ($P = 0.211$). Peak IAP during arm movement exceeded that during stepping and catching (main effect—task: $P = 0.001$; post hoc all: $P < 0.02$) (Table III).

Stepping

When stepping forward, foot elevation was preceded by increased Fz (anticipatory postural adjustment) followed by reduction to zero (foot off). Increased AS and TrA EMG (main effect—epoch: $P = 0.001$; post hoc all: $P < 0.04$) preceded Fz increase. SUS EMG exceeded baseline by the 10–20 msec epoch after Fz increase. EMG of all muscles increased prior to IAP ($P < 0.05$) (Fig. 4). Results were similar for visually detected onsets (Table II).

Load Catching

AS EMG and IAP increased above baseline 60–70 msec after loading (main effect—epoch $P = 0.007$; post hoc all: $P < 0.05$) (Fig. 5). SUS and TrA EMG exceeded baseline 90–100 msec after loading ($P < 0.001$). SUS EMG tended to increase at a similar time as IAP but failed to reach significance ($P = 0.18$).

DISCUSSION

This study provides new insight into the contribution of SUS to continence in men. Consistent with our first hypothesis, SUS EMG increased when continence was challenged by increased IAP. Several features highlight the relationship between SUS EMG and continence demand. First, SUS EMG and IAP correlated during repetitive arm movements. Second, SUS EMG increased before or shortly after IAP, depending on the task, supporting our second hypothesis.

Tonic Versus Phasic Activity of SUS

Concentric needle EMG recordings show tonic SUS activity at rest in men[16] and women[5,17] in supine, and in animals.[18] Tonic firing has been used to confirm electrode placement.[5,16] Transurethral surface electrodes are considered less sensitive to SUS EMG compared to needles in rats[18] and healthy supine females.[5] Although low amplitude activity may be present, no unambiguous SUS action potentials were observed in our

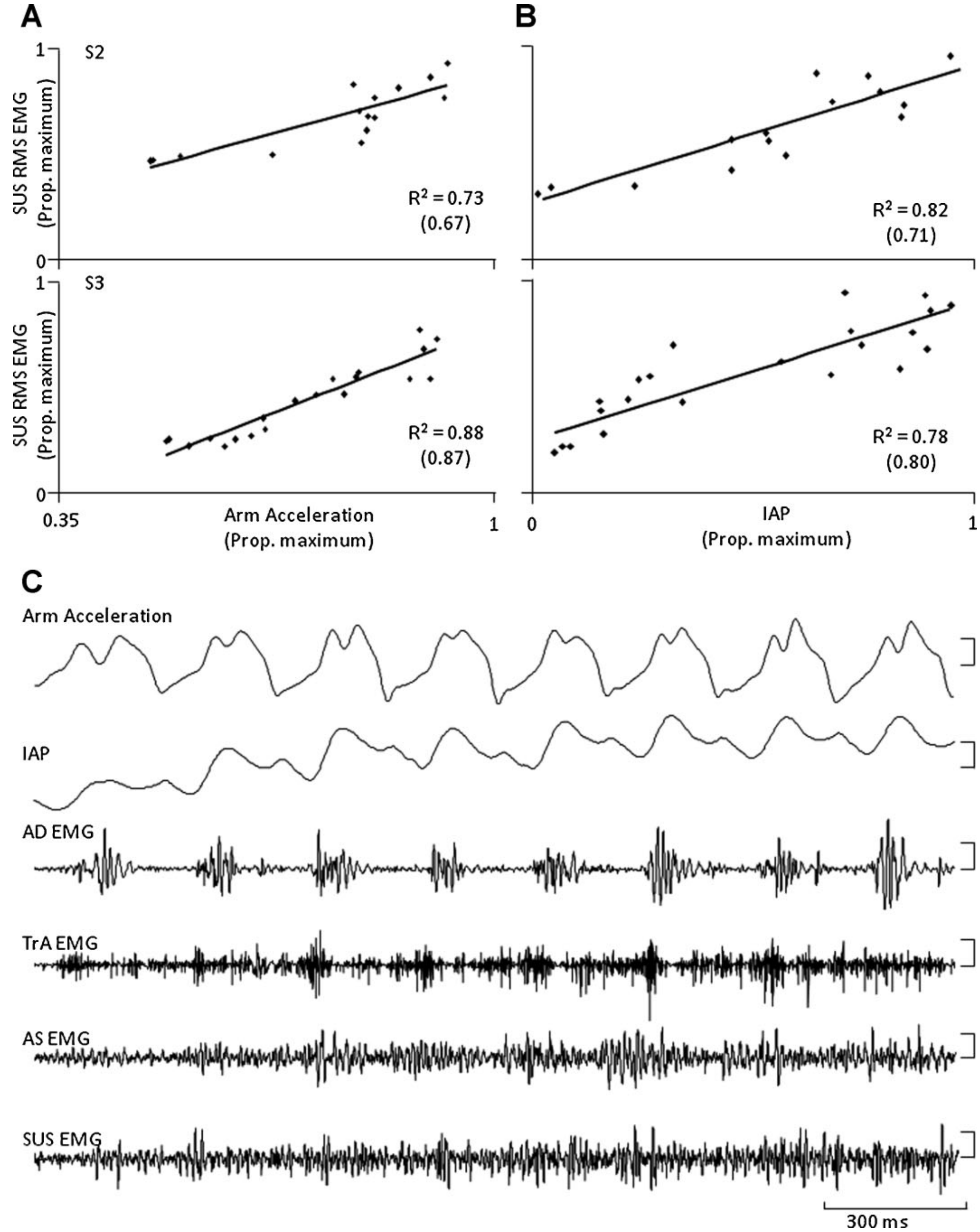

Fig. 2. Relationship between striated urethral sphincter (SUS) electromyographic (EMG) activity and arm acceleration (**A**), and between SUS EMG activity and intra-abdominal pressure (IAP) (**B**) during repetitive arm movements for two subjects with the strongest (S3) and weakest (S2) relationship. Linear regression is shown with R^2 value for forwards and backwards (in brackets) movements. Data are presented normalized to peak for the condition. Representative raw data from a single trial for the repetitive arm movement task is shown (**C**). Data for intra-abdominal pressure (IAP), anterior deltoid (AD), transversus abdominis (TrA), anal sphincter (AS), and striated urethral sphincter (SUS) EMG are shown. RMS—root mean square. Calibration: arm acceleration 40 m/sec^2, IAP 20 cmH_2O, AD and TrA 100 mV, AS and SUS 50 μV.

recordings at rest with an empty bladder. More obvious SUS activity may be detected with greater bladder volume or detrusor contraction, however; the lack of activity after 1.5–2 hr when the bladder would be expected to have larger volume suggests the lack of activity is not explained by empty bladder and more likely due to sensitivity of the electrode. Anesthetic (half-life 1.5–2 hr) may affect SUS activation, but this is unlikely as responses were recorded during postural tasks and no tonic activity was observed at the end of trials (~1.5 hr), when anesthetic effects were minimal. In contrast to some predictions,[1] SUS EMG increased during tasks with transient IAP increase.

These data show SUS EMG with postural challenges, which would both assist continence and enable IAP to increase, a

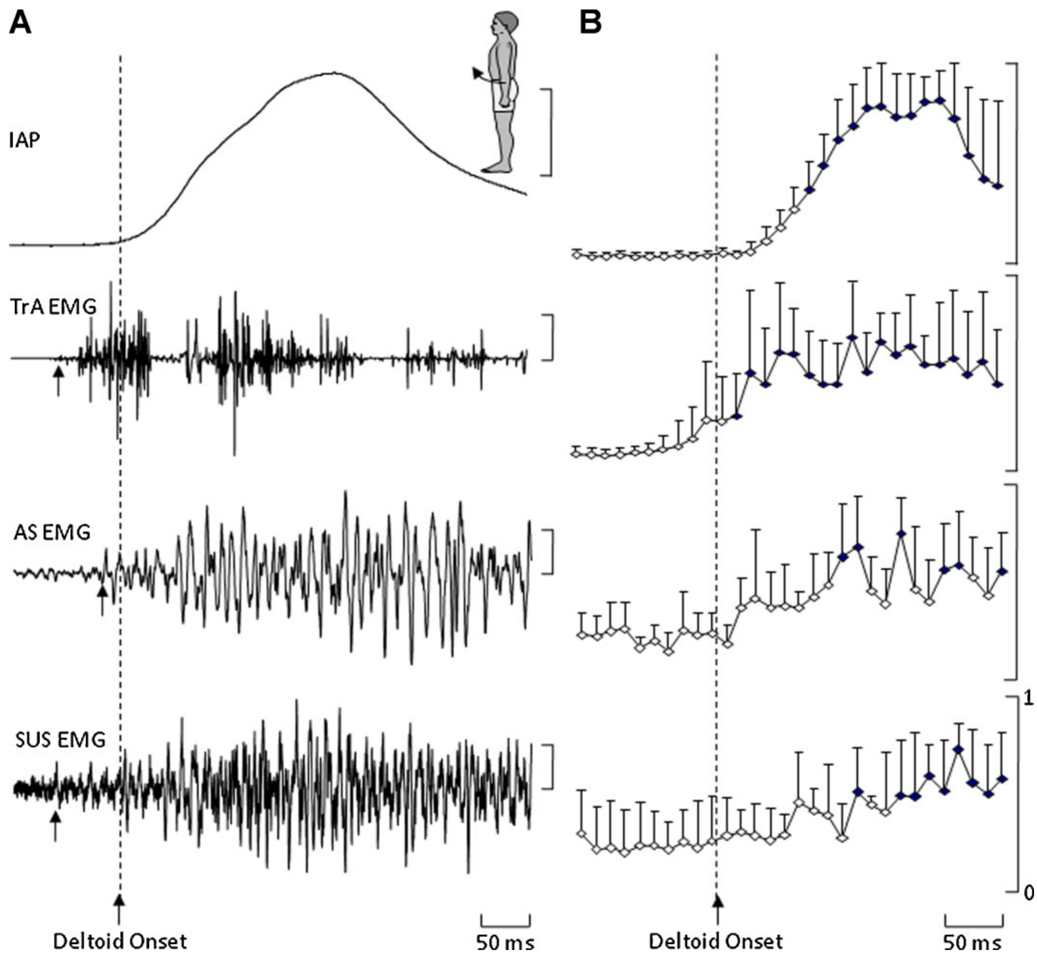

Fig. 3. Representative raw data from a (**A**) single trial and (**B**) group epoch data for the rapid arm movement task. Intra-abdominal pressure (IAP), transversus abdominis (TrA), anal sphincter (AS), striated urethral sphincter (SUS). Arrows under raw data indicate point of onset selected by visual detection. Filled shapes indicate epochs in which activity was significantly greater than baseline (epoch 1) indicting a significant increase from ongoing activity. Calibration: IAP 20 cmH_2O, TrA 1 mV, AS and SUS 125 μV.

feature critical for postural control. Our data support the relationship between SUS and postural demand. Repetitive arm movements with increasing acceleration showed a linear relationship between SUS EMG and IAP. This suggests SUS EMG amplitude is proportional to this task's demand on continence in agreement with AS data in coughing,[19] and vaginal and AS EMG with arm movements.[20] During stepping, SUS EMG onset occurred within 10 msec of Fz increase,[15] before any feedback was available from the movement. This must be pre-planned by the nervous system in anticipation of the task[21] and IAP increase. During arm movements SUS EMG onset followed deltoid by ~100 msec; after movement onset and afferent information about the task. This differs from vaginal and AS EMG in advance of deltoid EMG in women.[20] SUS EMG was less obvious with unpredictable loading, but still present. With loading, the postural adjustment cannot precede the task because its timing is unpredictable and SUS

TABLE I. Correlation (R^2) Between Arm Acceleration and RMS Muscle EMG in Repetitive Arm Movement Task

	Flexion			Extension		
Subject	SUS	AS	TrA	SUS	AS	TrA
1	0.74	0.87	0.78	0.7	0.82	0.9
2	0.73	0.72	0.78	0.67	0.43	0.58
3	0.88	0.73	0.69	0.87	0.67	0.88
4	0.77	0.51	0.57	0.74	0.65	0.75
5	0.77	0.8	0.78	0.74	0.56	0.51

SUS, striated urethral sphincter; AS, anal sphincter; TrA, transversus abdominus.

TABLE II. Time of EMG Onsets (msec) Relative to Onset of IAP Increase (Mean (Range))

Muscle	Rapid arm flexion	Rapid arm extension	Stepping
SUS	39 (−76 to 145)	39 (4 to 129)	−51 (−276 to 195)
AS	−31 (−71 to 9)	−43 (−270 to 44)	−60 (−507 to 290)
TrA	−32 (−76 to 67)	−15 (−74 to 21)	−109 (−356 to 146)

SUS, striated urethral sphincter; AS, anal sphincter; TrA, transversus abdominus; negative value, onset of the muscle prior to IAP increase.

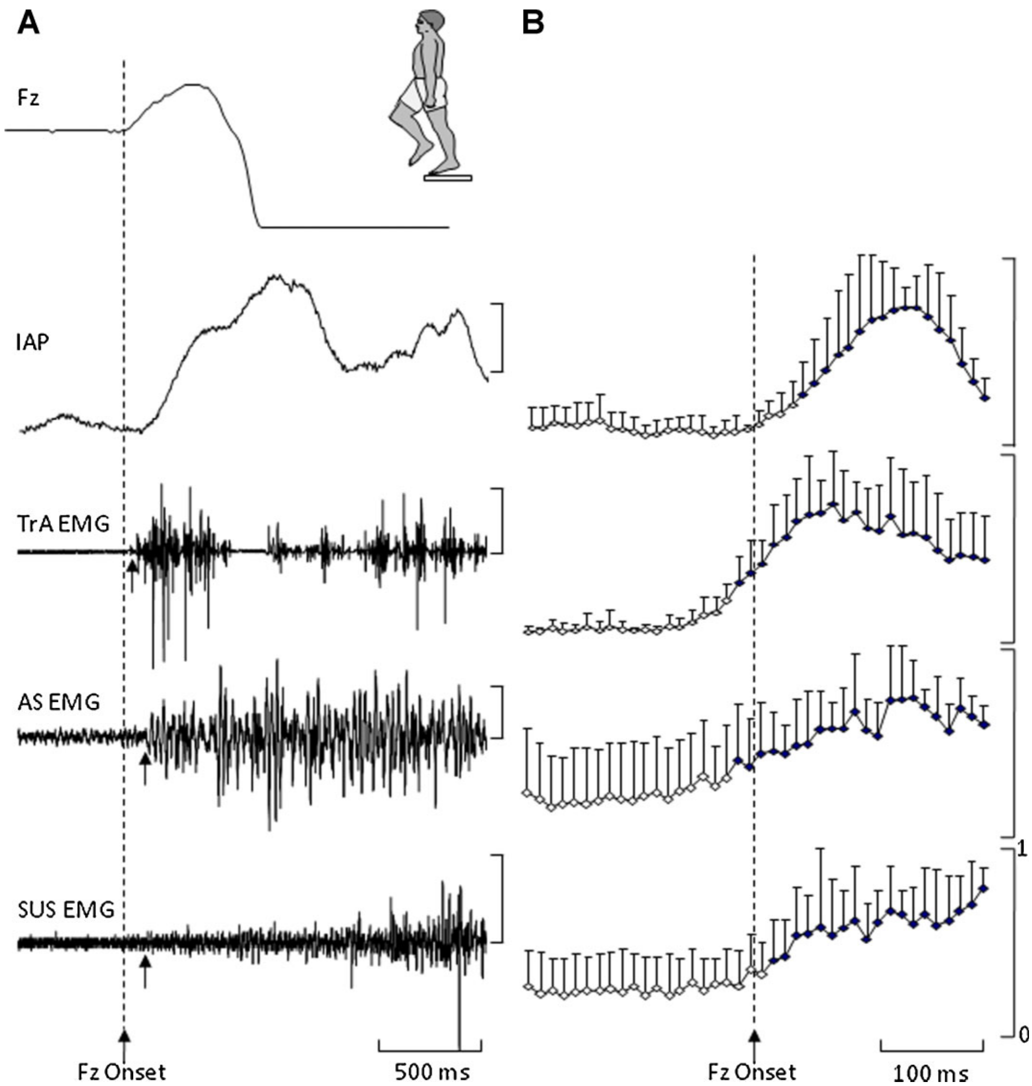

Fig. 4. Representative raw data from a single trial (**A**) and group epoch data (**B**) for the stepping task. Force under stepping foot (Fz), intra-abdominal pressure (IAP), transversus abdominis (TrA), anal sphincter (AS), striated urethral sphincter (SUS). Arrows under raw data indicate point of onset selected by visual detection. Filled shapes indicate epochs in which activity was significantly greater than baseline (epoch 1) indicting a significant increase from ongoing activity. Calibration: IAP 15 cmH_2O, TrA 125 μV, AS 50 μV, SUS 25 μV.

EMG increased 100 msec after loading as part of the perturbation response.

These data confirm SUS is active when postural challenges increase IAP. If such activity was compromised, as may be predicted in some clinical situations, it would not only have implications for continence, but also impact the ability to elevate IAP, with consequences for postural control.

TABLE III. IAP Amplitude (cmH_2O) Increase for Each Task

Subject	Rapid arm movement—flexion	Rapid arm movement—extension	Catching	Stepping
1	69.1	50.9	33.8	30.9
2	35.4	32.4	30.5	27.2
3	28.8	27.1	18.6	19.1
4	35.8	28.3	17.3	19.1
5	33.1	33.9	20.5	12.6
Mean (SD)	40.4 (16.3)	34.5 (9.6)	24.1 (7.5)	21.8 (7.3)

Relative Timing of Increases in IAP and SUS EMG

Two options are available for coordination of SUS activation and IAP: SUS activity may precede IAP to prepare for the demand; or increase in response to the demand. For SUS activation to precede IAP, the demand must be predictable. Previous studies have involved voluntary cough,[7,8,19,22,23] sniff,[7] and valsalva[22] efforts with predictable IAP increase, but results are not consistent across muscles of continence. Although some activate in advance of IAP during coughing (e.g., AS prior to IAP,[8] levator ani prior to abdominal muscles,[23] and urethral pressure before bladder pressure[22]), other data suggest a later onset (e.g., AS after rectus abdominis[7]).

This study is the first to evaluate SUS activity relative to IAP increases in males, and first to investigate SUS during tasks

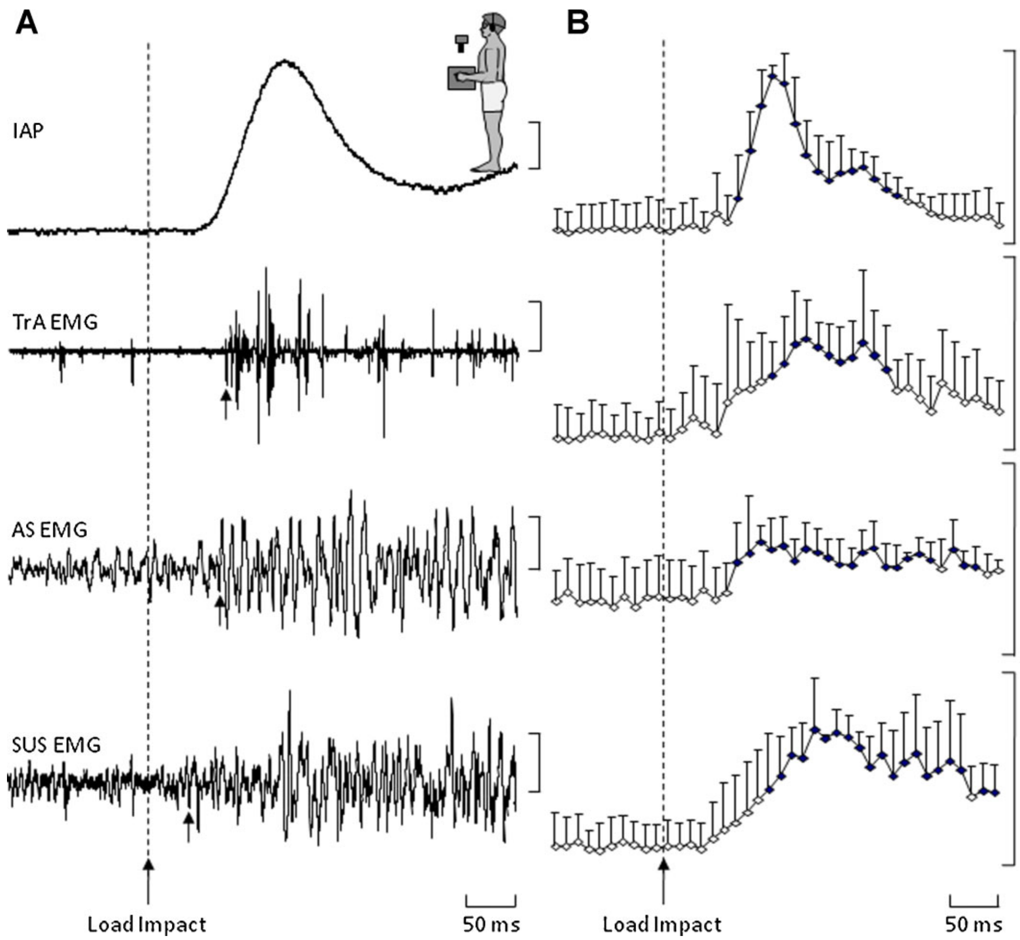

Fig. 5. Representative raw data from a single trial (**A**) and group epoch data (**B**) for the unpredictable loading task. Intra-abdominal pressure (IAP), transversus abdominis (TrA), anal sphincter (AS), striated urethral sphincter (SUS). Arrows under raw data indicate point of onset selected by visual detection. Filled shapes indicate epochs in which activity was significantly greater than baseline (epoch 1) indicting a significant increase from ongoing activity. Calibration: IAP 10 cmH_2O, TrA 250 μV, AS and SUS 25 μV.

other than coughing. In postural tasks, the relationship between SUS EMG onset and IAP varied. In most subjects, SUS EMG preceded IAP during stepping and repetitive arm movement. During single arm movements SUS EMG followed IAP and may be initiated in response to sensory feedback from IAP. SUS EMG preceded IAP in some individuals suggesting anticipatory activation is possible, but not mandatory. Later SUS onset relative to IAP in arm movement, despite greater peak IAP compared to other tasks, implies SUS onset is not dependant on IAP amplitude but is task-specific.

Interpretation of trunk-loading data is more complex. If IAP increases because of trunk movement from loading, SUS cannot activate in advance. Alternatively, if IAP increases because of the trunk muscle response, SUS may activate before IAP as part of the response. IAP increased 70 msec after unpredictable loading, before TrA but at a similar time to back muscles[24] suggesting IAP was increased by the postural response of trunk muscles which could include SUS activity to counteract the bladder pressure. Although epoch data show a later SUS response that IAP, an earlier response in some subjects suggests the SUS response is not a reaction.

Comparison of AS and SUS

IAP places demand on both fecal and urinary continence. Previous studies used AS EMG to infer SUS function assuming similar-timed activation.[25,26] Although data from stepping and trunk loading show similar-timed activation, AS preceded SUS in rapid arm movements. Earlier AS onset may be explained by differences in fecal and urinary continence mechanisms[27] and indicate AS EMG is not a surrogate for SUS EMG recordings.

Limitations

Surface EMG recordings include the potential for cross-talk from adjacent muscles.[5] Although the insertion technique ensured placement of the electrode adjacent to the SUS, some far-field activity from other muscles may have been present, and would be more likely to occur at high contraction levels. Furthermore, the recordings with this electrode may be less sensitive than concentric needles, but have sufficient sensitivity to detect activity of single motor units. Previous work has shown high-quality transurethral recordings using the catheter electrode described here at different levels of activation.[11] Lastly, we cannot exclude the possibility that activity of the SUS may have been affected by the presence of the catheter in the urethra.

We did not record from puborectalis; but its activity would be expected to relate to AS EMG recruitment. The modest sample size meant we only tested SUS control in younger men. Future studies might investigate healthy older men or those with certain pathologies and include bladder pressure in addition to IAP to investigate detrusor muscle contraction. Despite the small group data showed consistent responses for most tasks and had sufficient statistical power to identify changes in activity with the postural challenges.

CONCLUSIONS

This study used a new transurethral EMG electrode that can be stabilized in the urethra using suction to provide novel data of the activation of the SUS muscles during dynamic tasks. Data show SUS activity increases proportionally with IAP, which provides evidence that this muscle contributes to continence when IAP is increased and that postural control of the trunk involves SUS activation.

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