A study of the cortical processing of ano-rectal sensation using functional MRI

David I. Hobday, Qasim Aziz, Neil Thacker, Igor Hollander, Alan Jackson and David G. Thompson

1Gastrointestinal Science Group, Manchester University, Hope Hospital, 2Imaging Science and Biomedical Engineering, Manchester University, Manchester and 3Neuroscience Research Group, Institute of Psychiatry, London, UK

Summary
Investigation of human ano-rectal physiology has concentrated largely on understanding the motor control of defecation and continence mechanisms. However, little is known of the physiology of ano-rectal sensation. There are important differences in the afferent innervation and sensory perception between the rectum and anal canal. This suggests that there could also be differences in the brain’s processing of sensation from these two areas; however, this possibility remains unexplored. The aim of our study was to identify the cerebral areas processing anal (somatic) and rectal (visceral) sensation in healthy adults, using functional MRI. Eight male subjects with an age range of 21–39 years were studied on two separate occasions, one for rectal and the other for anal stimulation studies. Single shot gradient echo planar imaging was performed using a 1.5 tesla Phillips MRI scanner. For each subject, a series of 40 image sets containing 24 slices of the brain was obtained during periods of rapid phasic non-painful distension of the rectum or anal canal, alternating with rest periods, without stimulation. After motion correction, the images were analysed using cross correlation to identify the cerebral areas activated by the stimulus. Rectal stimulation resulted in bilateral activation of the inferior primary somatosensory, secondary somatosensory, sensory association, insular, peri-orbital, anterior cingulate and prefrontal cortices. Anal canal stimulation resulted in activation of areas similar to rectal stimulation, but the primary somatosensory cortex was activated at a more superior level, and there was no anterior cingulate activation. In conclusion, anal and rectal sensation resulted in a similar pattern of cortical activation, including areas involved with spatial discrimination, attention and affect. The differences in sensory perception from these two regions can be explained by their different representation in the primary somatosensory cortex. The anterior cingulate cortex was only activated by rectal stimulation, suggesting that the viscera have a greater representation on the limbic cortex than somatic structures, and this explains the greater autonomic responses evoked by visceral sensation in comparison with somatic sensation.

Keywords: ano-rectal; brain–gut axis; functional MRI; human; sensation

Abbreviations: ACC = anterior cingulate cortex; fMRI = functional MRI; p.s.i. = pounds per square inch; SI = primary somatosensory cortex; SII = secondary somatosensory cortex

Introduction
Studies of the neurophysiology of the ano-rectal region have concentrated largely on investigating the motor control of defecation. While defecation is controlled by a spinal reflex, maintaining continence while the rectum is full requires the voluntary contraction of the external anal sphincter. Therefore, while disorders of the pelvic floor musculature or spinal cord can lead to incontinence, maintenance of continence also requires volitional cortical control, which is dependent upon the sensory feedback from the ano-rectum. However, little is known currently about the cortical processing of ano-rectal sensation in man.

Despite the close anatomical relationship of the rectum and anal canal, there are clear differences in their innervation. The rectum is a visceral organ with an afferent innervation from the pelvic nerve consisting of unmyelinated C fibres and thinly myelinated A-delta fibres, which are only sensitive to rectal distension (Ness and Gebhart, 1990; Sengupta and Gebhart, 1994). The receptive field of C fibres is...
predominantly within the muscular wall of the rectum, while that of A-delta fibres is within the rectal mucosa (Sengupta and Gebhart, 1994). A-delta fibres are rapidly adapting and therefore respond to changes in rectal distension, while C fibres are slowly adapting and respond to the intensity of rectal distension (Mayer and Gebhart, 1994). Sensations from the rectum, in common with the other viscera, are perceived as poorly localized, often referred to somatic structures and result in greater autonomic response than somatic sensation (Ness and Gebhart, 1990). However, in contrast to all other gut organs, the rectum has an important sensory function. The anal canal has a somatic innervation from the pudendal nerve and this results in well-localized sensations. The presence of a high density of specialized receptors and afferent pathways allows for discrimination between different sensory modalities. These differences between rectal and anal sensation relate in part to the differences in their peripheral innervation and also probably to differences in their cortical representation, but this remains unexplored.

Using PET, Silverman and colleagues showed that the pattern of cortical activation differed between irritable bowel syndrome patients and healthy volunteers following rectal distension (Silverman et al., 1997). In healthy volunteers, both painful and sham rectal distension activated only the anterior cingulate cortex (ACC), while in irritable bowel syndrome patients only the prefrontal cortex was activated. Cortical areas responsible for spatial discrimination were not activated in either healthy volunteers or patients. The two other published studies of the cerebral processing of rectal pain have shown conflicting results. Rothstein and colleagues using PET in healthy volunteers showed activation of the pre- and post-central gyri, without cingulate or prefrontal cortex activation (Rothstein et al., 1996). Bouras and colleagues (Bouras et al., 1999) used single photon emission computed tomography in healthy volunteers, with a region of interest analysis, and showed ACC activation in all subjects and prefrontal cortex activation in half of the subjects. The somatosensory cortex, however, was not included in the region of interest analysis. There are no published studies of the cortical representation of non-painful ano-rectal sensation.

The aim of our study was to compare the cortical areas that process rectal (visceral) and anal (somatic) sensation in man using functional MRI (fMRI), in order to determine whether differences in the perception of sensations from these two areas could be explained by differences in their cortical representation.

Methods

Subjects

Eight healthy right-handed male volunteers with a mean age of 31 years (range 21–39) were recruited from the staff of the Department of Gastroenterology. None of the subjects had any gastrointestinal or neurological symptoms; none were taking any regular medication. All subjects were studied after giving written informed consent and with ethical committee approval from the Salford and Trafford ethical committee.

Ano-rectal stimulation

Both rectal and anal stimulation was performed using a 2 cm long latex balloon attached 1 cm from the distal end of a polyvinyl catheter with an external diameter of 5 mm. The balloon was inflated at a frequency of 1 Hz using a mechanical pump, especially constructed to be compatible with the MRI environment (Medical Physics Department, Hope Hospital, Manchester, UK). The inflation pressure generated by the pump could be adjusted from 0 to 25 p.s.i. The pump had a constant inflation time of 165 ms, so increasing the inflation pressure resulted in a larger volume of balloon inflation. For rectal stimulation, the catheter was positioned so that the middle of the balloon was 10 cm above the anal verge. For anal stimulation, the lower end of the balloon was positioned just above the anal verge.

MRI scanning

Scanning was performed using a 1.5 tesla Phillips ACS-NT MRI scanner in the Division of Imaging Science and Biomedical Engineering at Manchester University. The functional scans consisted of a series of 40 T²∗-weighted single shot gradient echo planar image sets each containing 24 contiguous slices [TR (repetition time) = 3000 ms, TE (echo time) = 50 ms, voxel size 3.5 × 3.5 × 3.5 mm]. During each scanning sequence, 30 s periods of stimulation were alternated with 30 s rest periods without stimulation. Preliminary studies had shown a marked attenuation of sensation and fMRI signal if the scans were extended over 2 min. This attenuation in sensation persisted with continued stimulation beyond 2 min and could relate to the physiology of rectal sensation and defecation. However, the aim of our study was to identify the cortical areas processing ano-rectal sensation. We therefore chose to perform two functional scans of 2 min duration in each subject, with a 5 min rest period between each scan as this was adequate for recovery of the fMRI signal, so maximizing our chances of identifying the cortical areas processing ano-rectal sensation. A T₁-weighted inversion recovery image set (TR = 6850 ms, TE = 18 ms, TI = 300 ms) was also obtained for each subject to provide anatomical information.

Protocol 1: rectal stimulation

In seven subjects, the rectal catheter was first inserted and the subject was then positioned in the MRI scanner. The balloon inflation pressure needed to produce a definite but non-painful rectal sensation was determined by increasing the pressure of rectal distension in steps of 1 p.s.i. Two functional scans separated by a 5 min rest period were then performed using this intensity of stimulation; the first functional scan started
30 min after inserion of the rectal catheter. Subjects were informed that after each scan they would be asked to describe the sensation experienced and its intensity.

**Protocol 2: anal canal stimulation**

This was performed on a separate occasion to protocol 1. Six of the original subjects and one additional subject (aged 36 years) were studied. The catheter was inserted and the balloon positioned within the anal canal. A stimulus intensity that produced a definite but non-painful sensation was determined as in protocol 1. Two functional scans separated by a 5 min rest period were then obtained at this stimulation intensity in each subject; the first functional scan started 30 min after insertion of the catheter. Subjects were informed that after each scan they would be asked to describe the sensation experienced and its intensity.

**Image analysis**

The images were transferred to a Sun Workstation for analysis using the Tinatool software package as fully described in Manchester University’s Web pages (http://www.niac.man.ac.uk/Tina). Each of the 40 image sets was aligned to the 20th image set by automated rigid body realignment. The algorithm employed maximizes the correlation between the two images in three orthogonal planes, and has been shown to correct adequately for motion in fMRI experiments (Thacker et al., 1999a). The images were then resliced using a 3D sinc algorithm based on a $5 \times 5 \times 5$ re-normalized kernel, which has been validated previously (Thacker et al., 1999b). An individual activation map was calculated from each functional image using cross correlation to a square wave template employing a cross correlation measure equivalent to that employed by other groups (Friston et al., 1994).

An averaged brain aligned to Talairach space was constructed by manually aligning high-resolution $T_2$-weighted MRI brain scans (TR = 2300 ms, TE = 80 ms, voxel size $0.45 \times 0.45 \times 3$ mm) from five normal subjects into Talairach space, using the Tinatool software package. The anterior and posterior commissure were identified by an experienced neuroradiologist; the MRI scans were then rotated so that both commissures were in the same horizontal plane. The scans were then scaled independently in the three orthogonal dimensions so that the brain size matched that of the Talairach brain.

The 20th image set, from each functional scan, was then aligned to this averaged $T_2$-weighted brain using rigid body realignment and linear scaling in the three orthogonal dimensions. As the individual correlation maps were aligned to the corresponding fMRI scans, the transformation matrix was used to transform the corresponding activation map into Talairach space. The activation maps from all subjects were averaged to form a group mean activation map. To account for intersubject variation in cortical anatomy, the group activation map was smoothed in the $x\text{--}y$ plane using a Gaussian filter with a kernel width of one voxel (3.5 mm). The statistical effects of all the processing were quantified by Monte Carlo simulation. A threshold with a significance value of $P < 0.001$ (uncorrected for multiple comparisons) was used to identify pixels in the filtered group activation map showing significant correlation with the stimulus. Only clusters of active pixels containing over three contiguous pixels were analysed so increasing the $P$ value of the reported activations, and reducing the chance of a type one statistical error (Forman et al., 1995). The Talairach coordinates for these areas were then calculated, and the cortical areas identified from the Talairach atlas (Talairach and Tournoux, 1988). These group mean activation maps were displayed on a 3D surface-rendered MRI brain scan using previously described software (Dimitrov, 1998).

**Comparison of rectal and anal sensory processing**

In order to determine whether there was a difference in the cortical areas activated by rectal and anal stimulation, a region of interest was drawn around areas of activation within the somatosensory cortex and ACC. The number of active pixels from each individual fMRI scan within each region of interest was counted. The numbers of active pixels in each region were compared statistically. Since there was a positive skew to the data, the Mann–Whitney $U$ test was used.

**Results**

**Protocol 1: rectal stimulation**

All the studies were completed without complication; the mean balloon inflation pressure was 11 p.s.i. (range 5--19). The stimuli were perceived as a deep-seated poorly localized non-painful pelvic pulsation. No discomfort or urge to defecate was reported during the rectal stimulation, and all subjects could clearly distinguish between the stimulation and rest periods.

Rectal stimulation (Fig. 1) produced significant activations bilaterally in the secondary somatosensory cortex (SII), sensory association cortex, ACC (Fig. 2) and insular cortex. There was an area of activation bilaterally bordering the inferior primary somatosensory cortex (SI) and Brodmann area 40, but with its centre in the inferior posterior SI (Fig. 3). There was also bilateral activation extending from the peri-orbital cortex to cover part of the anterior temporal lobe (auditory association cortex). In addition, there was bilateral activation of the prefrontal cortex, but in different regions of each hemisphere. The Talairach coordinates, Brodmann areas and the number of pixels in each activation cluster are given in Table 1.

**Protocol 2: anal canal stimulation**

All the scans were completed without complications; the average pressure of balloon inflation was 6 p.s.i. (range 3–15). The stimulus was perceived as a sharp well-localized non-painful peri-anal pulsation.

The areas activated by anal stimulation were the left SI
Fig. 1 Diagrammatic representation of the group mean activations for rectal and anal stimulation displayed on a 3D rendered MRI brain scan with the left frontal lobe removed to show the insular and anterior cingulate activations. This shows the similarities in activations in SII, insular and peri-orbital cortex, with the difference in position of the SI activation.

Fig. 2 The group mean activation in the anterior cingulate cortex following non-painful rectal stimulation superimposed onto an anatomical MRI scan aligned to Talairach space. (Fig. 2), bilateral SII, sensory association, insular, prefrontal peri-orbital and right premotor cortices (Fig. 1). Table 2 shows the Talairach coordinates, Brodmann areas and the number of pixels in each activation cluster. While the group mean SI activation for the whole group was left sided, there was a cluster of 10 pixels in the right SI which just failed to reach the significance threshold (Talairach coordinates –51, –14, +43).

Comparison of rectal and anal sensory processing
In comparison with rectal stimulation, anal canal stimulation resulted in a more superior SI activation, at a level above that previously identified as representing the hand (Derbyshire et al., 1997), and there was no activation in the ACC. Comparing the number of active pixels in the rectal and anal scans showed that the inferior SI had statistically greater activation with rectal stimulation and the superior SI with anal stimulation ($P = 0.029$ and $P = 0.021$, respectively). The ACC showed a strong trend for greater activation in response to rectal stimulation compared with anal stimulation ($P = 0.053$) (Table 3).

Discussion
The results of our study have identified a wide pattern of cortical areas that process ano-rectal sensation, including areas involved in spatial discrimination (SI and SII) and those involved in processing affective and cognitive aspects of sensation (ACC, insula and prefrontal cortex).

Despite evidence of convergence in the spinal cord (Ness and Gebhart, 1990) and thalamus (Bruggemann et al., 1994), animal studies have identified functional differences in the ascending spinal pathways serving visceral and somatic sensation. The dorsal columns have been shown to be functionally more important for visceral than somatic pain (Al-Chaer et al., 1998), and restricted lesions in the medial dorsal columns in man have been reported to reduce pelvic pain (Hirshberg et al., 1996). Our study has extended knowledge of this difference between visceral and somatic sensation by identifying differences in the brain regions processing these two sensory modalities.

Our study demonstrated activation on the border between the inferior part of the SI and Brodmann area 40 following rectal stimulation. Although the centre of this activation is within the SI, due to the inherent problems with the Talairach
atlas, a contribution from Brodmann area 40 cannot be excluded. The activation in the inferior part of the post-central gyrus following rectal stimulation in our study is an area similar to that activated by oesophageal sensation (Aziz et al., 1997; Binkofski et al., 1998) and swallowing (Hamdy et al., 1999b).

In contrast, the SI activation following anal canal stimulation occurred at a level superior to the area processing hand sensation (Derbyshire et al., 1997). This suggests that the differences in perception of visceral and somatic sensation are reflected by differences in their cortical representation, with visceral sensation being represented in the inferior part of the SI, and somatic sensation more superiorly. This is consistent with the results of single-cell recordings from the cortex of monkeys, which have demonstrated viscero-somatic convergence within the SI, but with the viscera only being represented within the inferior part of the SI (Bruggemann et al., 1997).

Previous PET studies of the cortical representation of oesophageal sensation have demonstrated asymmetry of SI activation (Aziz et al., 1997). Our study also demonstrated asymmetry in that the SI activation was lateralized to the left hemisphere for anal canal stimulation. However, the subthreshold cluster also present in the right SI suggests activation of this hemisphere in some subjects. In contrast, rectal sensation was represented bilaterally. However, it must be accepted that the use of group data for analysis would have reduced the chance of finding evidence for asymmetry, so we cannot exclude the possibility of lateralization in individual subjects. Asymmetrical control of ano-rectal motor function has also been demonstrated recently (Hamdy et al., 1999a).
Superior SI (and colleagues used fMRI to investigate the cortical

Inferior SI (identi

Furthermore, the only previously published study of rectal stimulation using PET and magnetoencephalography have identified activation in both SI and SII (Furlong et al., 1995; Aziz et al., 1997; Binkofski et al., 1998; Hecht et al., 1999). Furthermore, the only previously published study of rectal sensation identifying somatosensory cortex activation identified only SI activation (Rothstein et al., 1996). Binkofski and colleagues used fMRI to investigate the cortical representation of rapid phasic oesophageal distension and two intensities of tonic oesophageal distension (Binkofski et al., 1998).

This study demonstrated only SII activation with the low intensity tonic oesophageal distension, but both SI and SII activation with the other stimuli. This suggests that the differences in SI activation following visceral stimulation could relate in part to differences in stimulus intensities and frequencies used. It appears, however, that in most studies of human visceral sensation, both SI and SII are activated. The functional importance of these two areas of activation, however, remains to be determined.

Activation of the anterior insular cortex has been observed in previous studies of both somatic (Coghill et al., 1994; Derbyshire et al., 1997) and visceral oesophageal pain (Aziz et al., 1997). The insular cortex forms part of the limbic system, with efferent connections to both the cingulate and prefrontal cortices and afferent connections from the thalamus. Lesions of the insula result in loss of the affective response but preservation of the spatial discriminative aspects of pain. Direct electrical stimulation of the insula at surgery (Penfield and Faulk, 1955) results in visceral motor as well as sensory responses which include abdominal pain and nausea. It is unknown, however, whether these visceral sensations are a direct result of insular stimulation, or secondary to changes in visceral motor function. The insular activation in our study could therefore be due either to processing of the affective aspects of rectal sensation, or as a result of visceral sensory–motor responses due to rectal distension.

The ACC is often identified in human functional imaging studies of visceral (Aziz et al., 1997, 1999; Silverman et al., 1997) and somatic (Vogt et al., 1996; Derbyshire et al., 1997) pain processing, and has been considered as ‘the pain centre’. Direct electrical stimulation of the ACC results in changes in autonomic tone (Wall and Davis, 1951; Devinsky et al., 1995), which is mediated by efferent connections with vagal nuclei and sympathetic columns in the thoracic spinal cord. It is likely

Table 2: Details of the cortical areas, and number of voxels in each cluster, activated by anal canal stimulation

<table>
<thead>
<tr>
<th>Brodmann area</th>
<th>Talairach coordinates</th>
<th>Voxel count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left primary somatosensory cortex</td>
<td>1/2</td>
<td>+51 -14 +43</td>
</tr>
<tr>
<td>Left secondary somatosensory cortex</td>
<td>43</td>
<td>+48 -14 +13</td>
</tr>
<tr>
<td>Right secondary somatosensory cortex</td>
<td>43</td>
<td>-48 -14 +13</td>
</tr>
<tr>
<td>Left sensory association cortex</td>
<td>7</td>
<td>+15 -54 +60</td>
</tr>
<tr>
<td>Right sensory association cortex</td>
<td>7</td>
<td>-15 -54 +60</td>
</tr>
<tr>
<td>Left sensory association cortex</td>
<td>40</td>
<td>+51 -31 +20</td>
</tr>
<tr>
<td>Left insula</td>
<td></td>
<td>+40 +4</td>
</tr>
<tr>
<td>Right insula</td>
<td></td>
<td>-40 +4</td>
</tr>
<tr>
<td>Right prefrontal cortex</td>
<td>46</td>
<td>-41 +41 +10</td>
</tr>
<tr>
<td>Left prefrontal cortex</td>
<td>9</td>
<td>+54 +15 +33</td>
</tr>
<tr>
<td>Right prefrontal cortex</td>
<td>9</td>
<td>-54 +15 +33</td>
</tr>
<tr>
<td>Bilateral medial prefrontal cortex</td>
<td>9</td>
<td>0 +48 +36</td>
</tr>
<tr>
<td>Left peri-orbital cortex</td>
<td>47</td>
<td>+44 +22 -3</td>
</tr>
<tr>
<td>Right peri-orbital cortex</td>
<td>47</td>
<td>-44 +22 -3</td>
</tr>
<tr>
<td>Right premotor cortex</td>
<td>6</td>
<td>-41 +4 +43</td>
</tr>
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The inferior SI region of interest was drawn around the activation with rectal stimulation and the superior SI region around the activation with anal canal stimulation.

The significance of this lateralized cortical representation of midline structures is unknown, but might account for the observation that the somatic referral site of visceral pain is often asymmetrical.

The SII was activated by both rectal and anal stimulation. The SII receives afferents from the SI (Pons et al., 1987) and also directly from the thalamus (Stevens et al., 1993). There is evidence to suggest that for somatic sensation the functionally more important afferents are those from SI (Pons et al., 1987) and that SII is involved in the serial secondary processing of sensory information after primary processing has occurred in SI (Mauguiere et al., 1997). A recent magnetoencephalography study following oesophageal stimulation showed only SII activation (Loose et al., 1999; Schnitzler et al., 1999), suggesting that for visceral sensation SII may be functionally more important than SI. However, other studies of oesophageal stimulation using PET and magnetoencephalography have identified activation in both SI and SII (Furlong et al., 1995; Aziz et al., 1997; Binkofski et al., 1998; Hecht et al., 1999). Table 3 Comparison of the number of pixels with a correlation value >3 for the regions of interest within the anterior cingulate and primary somatosensory cortex (SI)

<table>
<thead>
<tr>
<th>Region</th>
<th>No. of active pixels (standard error)</th>
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<tr>
<td>Rectal stimulation</td>
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<td>Anterior cingulate</td>
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<tr>
<td>Superior SI (Z = +43)</td>
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that the ACC activation with painful stimuli is related to the generation of autonomic responses to the stimuli.

In the current study, non-painful rectal stimulation produced strong ACC activation. While studies of somatic sensation have only demonstrated ACC activation with pain (Coghill et al., 1994), studies of oesophageal visceral sensation have also demonstrated ACC activation during non-painful distension (Aziz et al., 2000). This limbic representation of non-painful visceral sensation could explain the greater autonomic reflexes and affective responses seen in response to visceral, compared with somatic sensation (Ness and Gebhart, 1990). ACC activation has also been demonstrated with the anticipation of visceral (Silverman et al., 1997) and somatic (Ploghaus et al., 1999) pain.

The ACC forms part of the limbic system and has also been shown in PET studies to be activated by sad emotions (George et al., 1995), and to be less active during depression (Mayberg et al., 1994). This suggests a role for the ACC in generating an affective response to a stimulus. In addition, the ACC has connections with the motor cortex, and it has been suggested that it plays an important role in selecting appropriate behavioural responses to a stimulus (Devinsky et al., 1995).

The prefrontal cortex is involved with cognition and memory, and receives inputs from the sensory association cortex. As the subjects were asked to rate the intensity of the stimuli, they were performing a cognitive task. It is therefore possible that the activation of the prefrontal cortex in our study is a reflection of this cognitive task. Silverman and colleagues (Silverman et al., 1997) hypothesized that altered cortical processing of rectal sensation occurs in irritable bowel syndrome based on their observation of activation in the prefrontal cortex in irritable bowel syndrome patients but not healthy volunteers. However, our study and that of Bouras and colleagues (Bouras et al., 1999) have demonstrated that this pattern of cortical activity can be a normal component of the processing of rectal sensation in health. Bouras and colleagues used a region of interest analysis over the prefrontal cortex, therefore the precise location of activation within this area cannot be determined in their study. As in our study, the prefrontal activation observed in the study by Silverman and colleagues was also in Brodmann area 10 (Silverman et al., 1997). However, because no Talairach coordinates for this activation were given in that study, a more detailed comparison of the location of activations in the prefrontal cortex with that observed in our study is not possible.

Both anal and rectal stimulation resulted in bilateral activation of the peri-orbital cortex. The peri-orbital cortex has connections with the limbic cortex, as well as receiving direct afferents from the spinal cord (Newham et al., 1996). This area is involved in maintaining homeostasis and in regulating autonomic function. The activation of the peri-orbital cortex seen in our studies is, therefore, likely to reflect changes in autonomic function in response to ano-rectal stimulation; however, this speculation remains to be investigated.

We have identified more areas of cortical activation with non-painful rectal stimulation than the previous studies of rectal sensation. This probably reflects methodological differences, in particular our use of repeated phasic distension which causes repeated stimulation of rectal stretch receptors, and so increased activity of ascending spinal pathways to the cerebral cortex. Our preliminary work confirmed that this also gives a larger fMRI signal change than tonic distension used in other studies (Silverman et al., 1997; Bouras et al., 1999). We have also used a shorter stimulation paradigm than the other fMRI studies, as our preliminary work demonstrated marked attenuation in signal response if the paradigm continued in excess of 2 min.

In conclusion, we have demonstrated a wide pattern of cortical areas processing anal and rectal sensation, including areas involved with spatial discrimination, attention and affect. In addition, we have shown that differences exist between the areas of somatosensory cortex responsible for processing the visceral and somatic components of sensation. The role of the anterior cingulate and prefrontal cortices in normal rectal sensation, and how this is modulated by attention and affect, need to be investigated further in order to develop a full understanding of the pathophysiology of diseases of ano-rectal function.

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