
On 4 June 1937, Wilder Penfield (1891–1976) read a paper to the American Neurological Association in Atlantic City in which he described results of stimulating the cerebral cortex in 163 awake adults undergoing intracranial surgery. Later that year he published, with Edwin Boldrey (1906–88), ‘Somatic motor and sensory representation in the cerebral cortex of man as studied by electrical stimulation’ (Brain 1937; 60: 389–443). Section 28 deals with ‘The quality of cortical sensation’: 369 responses elicited a sensation, the quality of which was not stated; 204 responses were described as tingling or electric; 131 stimuli induced numbness; 49 responses involved a sense of movement; and ‘eleven times the patient reported a sense of pain in one extremity or peripheral part; it was never severe… and never caused the patient to object’. Seventeen years later, and working with a different co-author, ME Faulk Jr, former research fellow at the National Institutes of Health, Penfield returns to his studies on the insula—the hidden cortex on the island of (Johann Christian) Reil (1759–1813)—regarded by early anatomists and physiologists as a centre for speech or taste.

Unlike the experimental animal which ‘cannot speak and must be anaesthetised’… ‘a patient usually shows a keen, and often impersonal, interest in the activity of his own cerebral cortex’. But their recordings, made during procedures planned with no purpose in mind except the cure and comfort of the patient, have to be opportunistic: ‘all too often when the golden opportunity presents itself, we lack the wit to ask the right question’!

Because Penfield has previously observed abdominal sensations and gastrointestinal mobility following stimulation of the insula, and others have developed the concept of a vagomotor centre regulating autonomic activities in the insular-orbital region—orchestrating a feeding pattern formed as a downward extension of motor representation in the cortex that engages mastication, salivation, swallowing, oesophageal contraction, and inhibition of respiration and contractions of the pyloric antrum—Dr Faulk has developed a technique for gastromotor recording (including gastric electric potentials sampled by a swallowed silver–silver chloride electrode in contact with the gastric mucosa), together with monitoring of respiration and intra-arterial blood pressure, during local anaesthesia in man. Now Penfield and Faulk report on all 36 patients treated surgically for focal epilepsy in whom stimulation of the insula was performed at the Montreal Neurological Institute (Canada) between 1945 and 1953, including those previously reported. They use a square wave generator producing current at a voltage slightly above threshold (0.5–5 V) at around 60 cycles per second applied for 2 ms. The patients have all had focal epileptic seizures considered to originate from the insula or adjacent areas of the temporal cortex and Sylvian regions.

Observations are made from 82 separate points of stimulation on the insular cortex: in 32 the patients report gastric sensory or motor phenomena; in 30 the experience is of specific somatic sensations; and in 20 there are other motor or sensory phenomena (Fig. 1). Whereas, the inferior portion of the insula is easily accessible and can be stimulated without disturbing nearby structures after removal of the anterior temporal lobe, only in two cases can the frontoparietal operculum be elevated to gain access and stimulate the upper and anterior limits of the insula. Visceral sensations evoked by stimulation and usually felt in the region of the ciphasial process, epigastrum or umbilicus are variously described: ‘something funny… gurgling… rolling… pain… nausea… scratching… sensation’ sometimes associated with components of respiration or bulbar elements of swallowing. The gastric motor responses include borborygmi, belching and vomiting. More objectively, the gastric contractions normally occurring at rates between 2 and 3 or 9 and 12 per minute are inhibited, and their tone and amplitude reduced, by stimulation of the insula in much the same way as occurs after dragging on the subdural veins—a painful procedure relieved by injection of the Gasserian ganglion or the use of pentothal, upon which manoeuvre gastric contractions recommence. Because the descriptions are so varied, Penfield and Faulk list the specific comments of each participant: for A Ki the effect is ‘my stomach is upset and I smell something like medicine’; for PM ‘my stomach went up and down like when you vomit’; and JC feels ‘this is it… going to bring up some gas… scared to death’. Although the sensations are elicited from single or multiple points of the exposed cortex, these cluster at the anterior and inferior portion of the insula (Fig. 2). Because abdominal sensation might follow stimulation, with inhibition or acceleration of gastric contractions that may also occur without the patient being aware, ‘we are unable to divide the insular cortex into primary gastric motor and sensory areas’. Furthermore, while closely related abdominal sensations result from stimulation at the foot of the precentral gyrus, no sequence...
that matches the acts and sensations of alimentation can be provoked by electrical stimulation of the Sylvian fissure and insula. GB, a French-Canadian aged 25 years kicked in the head by a horse in childhood has focal seizures manifesting as sensation under the left costal margin, a bad taste in the mouth and masticatory movements; electrocorticography and direct stimulation identify the origin of these sensations as the lower end of the precentral and postcentral gyri, which are removed. But the
seizures continue, much as before although without the perversions of taste; and, at further surgery, the various sensations can be elicited (including the abnormalities of taste) by stimulating the exposed posterior and superior insular cortex. ‘This case demonstrates the repeated reproduction of the…gastric aura from the surface of the island of Reil following excision of the inferior Rolandic region and superior bank of the Sylvian fissure.’

Somatic sensations described with stimulation of the insula—usually contralateral but sometimes bilateral or unilateral—are ‘tingling…warmth…numbness…tightness…vibration…shock . . . or simply sensation’ felt in the head and mouth sometimes spreading to contiguous parts of the trunk or arm. But there are some consistent patterns: stimulation around the inferior posterior part of the central sulcus of the insula produces sensation in the contralateral hand and fingers; and stimulation anterior to the central sulcus leads to awareness in the lips, mouth and throat sometimes spreading bilaterally into the arms. B McK, aged 28 years, offers the best opportunity for topographical comparisons. Following meningitis in infancy, she has had seizures characterized by abdominal sensations including belching and flatulence, a peculiar sensation in the lips and both hands with absence followed by automatisms or a major convulsion. Whilst sensations typical for those normally elicited by stimulation of the second-sensory cortex in man can indeed be reproduced, these are not reminiscent of her seizures which electrocorticography suggests arise deep to the Sylvian fissure; and the source is localized after removal of sufficient tissue from the second-sensory cortex and first temporal convolution to an abnormal island of Reil which is then exposed in its entirety. After regional stimulation producing a variety of sensations in the tongue, nose and arms, mainly on the left, and with the most sensitive area being the superior border, the insula is also removed. This difficult procedure is also carried out in three other cases. Generally it is well tolerated and without causing any additional neurological deficits. WG, aged 41 years, with a difficult birth and subsequent head injury, has a 20-year history of epilepsy characterized by sensation above the left eye, an explosion of light and a rising sensation from the umbilicus followed by automatisms or a major convulsion. Whilst sensations typical for those normally elicited by stimulation of the second-sensory cortex can indeed be reproduced, these are not reminiscent of her seizures which electrocorticography suggests arise deep to the Sylvian fissure; and the source is localized after removal of sufficient tissue from the second-sensory cortex and first temporal convolution to an abnormal island of Reil which is then exposed in its entirety. After regional stimulation producing a variety of sensations in the tongue, nose and arms, mainly on the left, and with the most sensitive area being the superior border, the insula is also removed. This difficult procedure is also carried out in three other cases. Generally it is well tolerated and without causing any additional neurological deficits. WG, aged 41 years, with a difficult birth and subsequent head injury, has a 20-year history of epilepsy characterized by sensation above the left eye, an explosion of light and a rising sensation from the umbilicus followed by automatisms or amnesia. B McK, aged 28 years, offers the best opportunity for topographical comparisons. Following meningitis in infancy, she has had seizures characterized by abdominal sensations including belching and flatulence, a peculiar sensation in the lips and both hands with absence followed by automatisms or a major convulsion. Whilst sensations typical for those normally elicited by stimulation of the second-sensory cortex in man can indeed be reproduced, these are not reminiscent of her seizures which electrocorticography suggests arise deep to the Sylvian fissure; and the source is localized after removal of sufficient tissue from the second-sensory cortex and first temporal convolution to an abnormal island of Reil which is then exposed in its entirety. After regional stimulation producing a variety of sensations in the tongue, nose and arms, mainly on the left, and with the most sensitive area being the superior border, the insula is also removed. This difficult procedure is also carried out in three other cases. Generally it is well tolerated and without causing any additional neurological deficits.

What has been learned from these studies designed to examine the relationship of the island of Reil to function of the gastrointestinal tract using an electrogastrograph passed preoperatively into the patient’s stomach? ‘It has been a difficult task to delimit the functional areas of cortex within the fissure of Sylvius and in the circular sulcus that surrounds the insula.’ Those studies have already been mapped out tentatively by Penfield in his monograph with Herbert Jasper ([1906-99]: Epilepsy and the Functional Anatomy of the Human Brain, 1954; Fig. 4]). Since in its anterior and superior relationships, the insular cortex is continuous with that of the frontal and parietal lobes, and with the temporal cortex and Heschl’s transverse gyrus below and at its posterior margin, respectively, it is to be expected that epileptic discharges will include gustatory and olfactory experiences, hallucinations of past experience, illusions of the present and automatisms. Less sure in Penfield’s mind are the limits of the second-sensory cortex and whether this overlies the insula; and the representation of motor control over the stomach attributable to the insular cortex. It follows that stimulation may excite neighbouring areas, thus confounding interpretation of the functions of the insula itself; previous damage may have distorted the normal functional arrangements; and chronic epileptic discharges may have altered thresholds for response of the underlying cortex either through ‘epileptic facilitation’ or spread from insensitive tissue to the nearest responsive neurons. From amongst the plethora of responses actually observed can be distinguished two that are consistent: ‘the visceral (sensory and motor); and the somatic (sensory)’. More than a third of the stimulations have yielded sensations referred to the abdominal cavity often with alterations of gastric motility indicating ‘that the island of Reil has some sort of motor control over gastrointestinal function without neuronal detour to adjacent cortical areas’. With two exceptions (one involving the postcentral gyrus and the other the hippocampus; but neither with awareness), this has not been seen when stimulating other parts of the cerebral cortex. Limitations of the procedure—surgery in awake humans—have not made it possible to chart the sequence of alimentary motor events as seen in, for example, the dog. That said, it is reasonable to conclude that representations of chewing, swallowing and salivation lie just above and extending into the
Sylvian fissure; sensation of the mouth and pharynx in the opercula; and taste where the upper Sylvian bank joins the insula. The high frequency of somatic sensations following stimulation of the insula is surprising since these are seldom described as part of the epileptic seizure. Tentatively, Penfield and Faulk discard the possibility that some of these responses may arise from spread of the electrical stimuli to the second-sensory cortex itself. When the superior portion of the insula is exposed, the responses suggest that the second-sensory cortex involves both the lower part of the upper Sylvian bank and the upper part of the insula itself (Fig. 5). Given their conclusions on topographical representations of the Sylvian bank—arm above leg which, in turn, lies closest to the insula—it is odd that somatic sensations are almost never experienced in the lower limb. Rather, stimulation posterior to the central sulcus elicits contralateral upper limb sensations whereas those anterior to the sulcus produce bilateral awareness in the lips, tongue and pharynx or, occasionally, both arms. Rarely does stimulation of one point on the insula lead to both visceral and somatic sensations.

Penfield and Faulk acknowledge that their analysis is ‘greatly handicapped by the fact that the superior portion of the insula has so rarely been exposed’. Their aim is to describe the functions

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**Figure 4** Functional areas in insular and circumsylvian regions. Some of the boundaries which separate these areas from one another are, as yet, not clearly established. Reproduced from Penfield and Jasper, *Epilepsy and the Functional Anatomy of the Human Brain*, 1954; Fig. X-3, p. 426 (From Penfield and Faulk, 1955).

**Figure 5** Localization of second-sensory representation (stippled) of arm and leg on superior bank of fissure of Sylvius of man. It is probable that there is a face representation above arm and that the stippling should be carried more posterior within the Sylvian fissure and down to the insula. Reproduced from Penfield and Jasper, *Epilepsy and the Functional Anatomy of the Human Brain*, 1954; Fig III-27, p. 87 (From Penfield and Faulk, 1955).
of the insula and to take forward into man experimental studies indicating the presence of a vagal-motor centre in the ‘insular-orbital region’. In 1937, Penfield and Boldrey concluded: ‘The fact that only eleven times out of well over 800 responses did the patient use the word pain to describe a cortical sensation probably indicates that pain has little, if any, true cortical representation’. Nothing in his subsequent work qualified Penfield’s conclusion; and his work remains influential in shaping ideas on the cortical representation of pain. That conclusion is now challenged by Laura Mazzola and colleagues from Lyon (France) who, in an occasional paper, report on 4160 cortical stimulations during the presurgical evaluation of epilepsy in 164 consecutive patients of whom 1.4% report pain; those stimulations are concentrated in the medial part of the parietal operculum and neighbouring posterior insula a deep cortical region largely inaccessible to the intraoperative stimulation of the cortical surface carried out by Penfield after resection of the parietal operculum (see page 316 and 631).

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