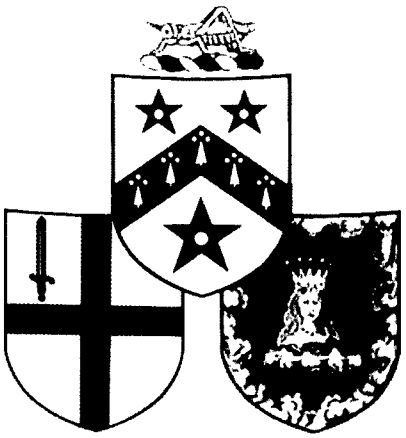
G R E S H A M

C O L L E G E



EXPLORING THE BRAIN

Lecture 1

BUILDING A BRAIN

by

PROFESSOR SUSAN A. GREENFIELD MA DPhil
Gresham Professor of Physic

29 November 1995

GRESHAM COLLEGE

Policy & Objectives

An independently funded educational institution, Gresham College exists

- to continue the free public lectures which have been given for 400 years, and to reinterpret the 'new learning' of Sir Thomas Gresham's day in contemporary terms;

- to engage in study, teaching and research, particularly in those disciplines represented by the Gresham Professors;

- to foster academic consideration of contemporary problems;

- to challenge those who live or work in the City of London to engage in intellectual debate on those subjects in which the City has a proper concern; and to provide a window on the City for learned societies, both national and international.

Gresham College, Barnard's Inn Hall, Holborn, London EC1N 2HH
Tel: 020 7831 0575 Fax: 020 7831 5208
e-mail: enquiries@gresham.ac.uk

SUSAN GREENFIELD

GRESHAM LECTURE 1:

BUILDING A BRAIN

The 1990s have been proclaimed the 'Decade of the Brain' in order to 'enhance public awareness of the benefits to be derived from brain research'. This increasing attention on the brain is reflected in the growing number of scientists, 'neuroscientists', exploring how it might work. In 1970, attendance at the annual meeting of the Society for Neuroscience was in the region of 1500, whereas in 1994 it numbered well over 21,000.

The question of 'how the brain works' is far too global and vague to have any meaning in terms of setting up specific experiments. What we need to do instead, is to tackle more specific questions which will in the end contribute to a final understanding of this secretive mass of tissue in which is somehow locked the essence of our personalities. The question we shall explore in this lecture arises from the most obvious feature of the brain, that it is made up of distinct compartments. Do each of these regions have a separate function and if so, what are they?

Imagine you were looking at a brain in your hands: what you would be holding would be a creamy coloured, wrinkled object weighing just over one kilogram, on average about 1.3 kilograms. Normally the brain has the consistency of a raw egg with an overall ground plan that is

always the same. There are two clear halves, so called hemispheres, that seem to sit around a kind of thick stalk (brainstem). This brainstem eventually tapers down to become the spinal cord. The different regions of the brain enfold around the brainstem a little like the layers of an onion. They are divided up by neuroscientists almost as though they were countries, by boundaries. Often these boundaries are very obvious: one might be a fluid-filled cavity in the middle of the brain, another a clear change in texture or colour.

The brainstem is recognisable as a landmark across most species, and in general there is a basic and consistent format. However, an important clue to brain function is that across species there is nonetheless an important difference in the outer layer of the brain, the cortex. In more sophisticated animals the cortex is folded, 'convoluted', so that its surface area has been able to increase whilst respecting the confines of a relatively small skull. The rat cortex is the size of a postage stamp, that of the chimp is the size of an A4 piece of paper, whereas the human brain has dramatically quadrupled! Since humans have more time to think and indulge in thinking, far more than any other species, the cortex must therefore in some way be related to thinking.

Of all the regions of cortex, the 'prefrontal cortex' at the front of the brain has demonstrated the most spectacular growth: during mammalian evolution it has increased 3% in cats, 17% in chimps but a staggering 29% in us humans. An early clue as to the actual function of

the prefrontal cortex comes from a chance event that happened in the last century in 1848 in Vermont.

One Phineas Gage was a foreman on a railway gang and it was his job to push dynamite down a hole in order to explode, eventually, any obstacles that blocked the passage of where the track was going to be laid. In order to apply the dynamite, Phineas had to use a rod-like object called a tamping iron, which in this case was some 3 ft 7 ins long, and at its widest point was 1.25 ins wide.

What happened one day was that by chance a spark ignited the dynamite prematurely and exploded the dynamite. Although there was a very hefty explosion Phineas, surprisingly, survived, but not without some injury. Phineas had been holding his head to one side, such that the premature ignition of the dynamite drove the tamping iron up through the left hand side of his head. The iron went through his cortex in the front of the brain, severely damaging his prefrontal cortex. Amazingly, after a brief period of unconsciousness, Phineas came round and seemed to be remarkably unaffected by such a dramatic course of events.

But as time went on people started to notice a difference. Whereas before he had been a co-operative and a friendly person to work with, Phineas now became overbearing, indecisive, arrogant, obstinate, uncaring for others. In fact he eventually left his job on the railway and

ended up living out the rest of his life as a fairground freak, touring around with the tamping iron sticking out of his head.

It is really quite hard to sum up in one word what the function of the prefrontal lobes are. Even compared to our nearest relative, the chimpanzee, with whom our DNA differs by only 1%, areas such as the prefrontal cortex are several fold greater. Clearly, these frontal areas are associated with subtle functions of the brain, 'cognitive processes', that do not have a direct relation to the senses or to movement.

On the other hand certain areas of the cortex do seem to have a clear correspondence with brain inputs and outputs. For example, cells in the retina send out electrical signals along outgoing fibres deep into the brain, to a region named after the Greek for room, the thalamus. The thalamus then sends signals on to a special region of the cortex, the outer layer at the back of the head, the 'visual cortex'. This sequence of events, this passing on of an electrical signal, somehow underlies how we see. Exactly how the brain process an object in our visual field, is still an area of intense investigation. However, there are certain cases of people that unfortunately have had loss of certain specific parts of the visual cortex, who have thereby given neuroscientists some very helpful and intriguing insights into understanding the process of vision.

There was one particular case of a lady in her forties who, due to a stroke, had cells damaged in a highly localised region within the visual cortex: but she could still see normally. The interesting aspect of her

condition was that although she could see everything absolutely normally, she was unable to see objects in motion. If, for example, she poured out tea, it apparently seemed frozen like a glacier. Indeed she was unable to engage in this activity because she could not stop pouring: she could not see the level of the fluid in the cup rising sufficiently well to know when to stop. On the other hand, its not as if this lady had a problem in detecting movement generally because, if something was presented to her by means of sound or by touch, then she could detect it as movement.

So it seems that although this particular patient could see colour and form, she was unaware of movement. Comparable situations have been reported since the First World War, when many more people increasingly displayed the consequences of head injuries, due to the wounds of battle. In certain cases, patients could this time see movement, but no shape or colour. Similarly there are patients who can see form and can see movement but who cannot experience colour. The whole world to them seems monochromatic, just in shades of grey.

Thanks to these cases, current thinking is that perhaps we process vision partly 'in parallel', that is to say we are processing visual signals simultaneously but in different parts of the brain. Different aspects of our vision, form, colour, and movement seem to us a cohesive whole, but are actually processed, at least in part, by different systems connecting up, through relays, the retina with the back of the head.

Similarly, different brain regions appear to control different aspects of movement 'in parallel'. One is the cerebellum, the little brain at the back of the main brain. The cerebellum is important for movements where there is a steady, ongoing feedback from your senses: in this sort of movement you would be checking all the time on what your senses are telling you in order to modify your movement as it was being generated. Imagine, for example, that you had to trace a complex pattern on to paper. Your hand would be under constant surveillance from your eyes: this would be an example of a 'tracking movement'. If people have damage to the cerebellum, then they are unable to perform these kind of movements. Such movements are intimately linked in to the information from the senses, thus entailing 'sensory-motor' co-ordination needed, for example, for a tracking movement.

However, there is also another type of movement which is not modified by continued, up-dated information from your senses. These are movements that once initiated, can no longer be modified. This class of movement is referred to as a 'ballistic' movement because it resembles a cannonball coming out of a cannon mouth, once initiated it cannot be modified. When, for example, someone takes a golf swing, the ball quite often stays mockingly on the tee because the movement cannot be modified: it is, literally, hit or miss. Another example of a ballistic movement in everyday life would be swatting a fly.

The area of the brain associated with these ballistic movements is a group of brain regions known as the 'basal ganglia'. When these particular

regions are damaged, there are devastating consequences for movement. According to the part of the basal ganglia that is damaged, there can be wild, involuntary movements (Huntington's Chorea), or the opposite, difficulty in moving at all, combined with muscle rigidity and tremor (Parkinson's disease).

Another region important in the control of movement is the motor cortex. The motor cortex controls fine movements by sending signals directly to the digits in question, as well as indirectly influencing movements generally, via four nerve 'motorways' descending down the spinal cord from centres in the brainstem. In a very organised fashion, parts of the motor cortex are allocated to controlling different parts of the body. You might think that such an allocation would correspond to the size of the body part in question: presumably a tiny area such as the hand would be controlled by only a tiny part of motor cortex, whereas a large area like the back would have a large allocation of motor cortex to control its movements. However there is a disproportionate representation of the body within the motor cortex. The critical factor is not size of the particular part of the body, but rather the precision of the movement that that body part needs to make. The more precise the movements that you need to make, then the larger the area of the brain that is devoted to them. Hence the hands and the mouth have an enormous allocation within the motor cortex compared to, say, the upper arm or the small of the back, which does not seem to have much representation at all.

So we can see then that movement can be split up, although we are not consciously aware of it happening, into different types of movement, and these different broad classes of movement are in turn controlled by different basic brain areas. However even these different brain areas, such as the cerebellum and basal ganglia, do not function as autonomous units. The cerebellum for example has strong connections with another part of the cortex which lies in front of the primary motor cortex (lateral premotor area) whilst the basal ganglia is in intimate contact with an area of cortex known as the 'supplementary motor area'. Indeed, damage to the supplementary motor area can lead to impairments strikingly similar to Parkinson's disease.

Just as there are motorways leaving the brain, via the spinal cord to control muscles and hence movement, so there are incoming signals that are sent up the spinal cord into the brain: these signals relate to touch and pain, and are referred to as the 'somatosensory' system. Triggered by the point of contact with the pain or touch on a specific area of skin, peripheral nerves within the skin relay signals to the spinal cord. The impulses come up from the spinal cord and finally arrive at the top of the head, in a special part of the outer layer of the brain, the cortex, known as 'the somatosensory cortex'. There are two major incoming motorways into the brain: one, the evolutionary older, is related to pain and temperature as well as carrying some information about touch, whilst the newer system carries more precise signals relating to touch. Different neurons in the somatosensory cortex correspond to the sense of touch in different parts of the body. One might expect that one's hand, which is a

relatively small part of the body, would have neurons that register impulses on the hand in a very small part of the cortex. However, just as we saw for the motor cortex, there is no direct matching of an area of your body to an area of the somatosensory cortex. The hands and the mouth have an enormous, vastly disproportionate representation.

For both movement and touch, this biased allocation of neurons makes sense. It is most important in our lifestyle that we should be able to move our hand and mouths with enormous precision. Similarly, it is important for our mouths and our hands to be most sensitive to touch because eating and feeling things with our hands are among our most basic and vital behaviours. In the areas of hand and mouth, as opposed to small of the back for example, it is most important that we have a very exquisite sense of touch.

Just as there is no one centre for control of movement, nor indeed for each of the senses, it is not surprising that our most sophisticated functions are also processed 'in parallel'. In 1861, in France, the neuroanatomist and anthropologist Paul Broca examined a man who was unable to speak. This man could only say 'tan': he couldn't pronounce any other words, hence he was referred to as 'Tan', even though his real name was Leborgne. Tan earned his place in history because six days after the examination he actually died, thereby giving Broca the chance to examine his brain. It turned out that the area of the brain damaged was a small region towards the front of the left hand side of the brain. Henceforth this part of the brain became known as 'Broca's area'.

A few years later, Carl Wernicke discovered a different type of speech problem, that was associated with damage to a completely different part of the brain. In this case the patient, unlike Tan, could articulate words perfectly. The only problem in 'Wernicke's aphasia' is that the speech is often jargon. Words are jumbled together in an incoherent sequence and frequently new words are invented with no apparent meaning at all. Nowadays, it is possible to monitor different brain regions at work in conscious subjects: there are many brain regions that contribute to our ability to understand and generate language. In general, most of our everyday activities that we perceive as a single act, such as 'remembering', nonetheless involves the concerted contributions of several brain regions. It is still one of the greatest mysteries in neuroscience how the activities of disparate regions 'come together' to give a sense of a unified function.