

EVEN LESS LIKE A HUMAN IN 2006 THAN IN 2002 – AN UPDATE OF RECENT ADVANCES IN COGNITIVE NEUROSCIENCE

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I.E.Addison, MA, PhD Currie Lodge, Ireby, Wigton, Cumbria, CA7 1DS

PART 1 - The Cortex and Comparative Psychology

SUMMARY

How human are animals? Can they worry like us? Few would deny that this depends on their brains. First, what does neuroanatomy say of their mental apparatus compared to ours; second, what does comparative psychology say of what mental abilities lie behind their observed behaviour.

Evidence from neuroanatomy:

The effects of injury, disease and surgery together with very recent techniques including those which 'look' at the brain in action (neuro imaging), show that in humans the cortex, in particular the frontal lobes (FLs), is necessary for specifically human mental abilities. These abilities would include imagination, abstract thought, sense of a personal past and future and conscious emotion, hence would determine psychological trauma as we would experience it. There is a marked reduction in size of the FLs in apes compared to humans, yet more reduction in monkeys compared to apes and a much, much greater diminution and other changes in moving from these primates to other mammals (size, proportion of brain, complexity of 'wiring', types of nerve cell etc) On these grounds alone one would expect apes to be less able than us to understand implications, imagine disaster, immediately fear the worst, be haunted by the past, in short to worry, and other primates even less so. Non-primates would be way, way behind.

Evidence from experimental psychology: (To be distinguished from untested interpretation of observed behaviour).

This sections refers mainly to primates, as only they manifest much of what is to be studied, but is of general interest, as being our closest animal relatives, they must indicate an upper limit for animal ability to worry as a human, Possibly for apes (still a huge argument over them!) but agreed for other primates, psychological studies suggest reduced, or sometimes absent human mental capacities such as self awareness, awareness of others mental intentions, thinking beyond the immediate future and capability of abstract concepts. If this is where primates are, what of non-primates which neuroanatomy would put so far behind?

1. THE DRIVING SEAT IS IN THE FRONTAL LOBES

Evidence from humans with damaged FLs.

"*Frontal Lobe Syndrome*" [5] reduction/loss, of the following [6] :

- Self-awareness: an image in a mirror is someone else.
- Mind-reading: no sense of the feelings, intentions of others.
- Autobiographical memory: no memory of personal events.
- Awareness of the past/future: the future is just 'not there'.
- Ability for 'forward thinking': inability to plan, follow instructions.

- Behavioural flexibility, especially beyond the obvious.
- Emotionality/emotional guidance: take risks - no 'nerves'.
- Imagination: e.g inability to do a job requiring 'lateral' thinking.
- Feelings of pain: awareness but "it no longer matters".

Evidence from intact FLs in action.

Neuroimaging 'pictures' the normal brain in action - confirming and expanding the conclusions from pathology.

- as problems get more complex, imagination is required, self-reflection is activated – Pre frontal cortex (PFC) of the FLs lights up. [8, 25]
- specific areas of which are involved in different types of problem [9].

SUMMARY. In humans an intact PFC is necessary for thinking and feeling to the full. It can be imaged doing just that in normal subjects while subjects in whom it is damaged have been described as 'feckless' in their carelessness over the future. It may be significant for imagining life with less PFC, that patients may not know that they have lost any faculties [7].

2. COMPARATIVE NEUROANATOMY OF THE CORTEX AND FLs IN PARTICULAR

Differences between 'the rest' and primates:

- 'explosive' increase in size of the primate cortex. [11. 24]
- increased thickness of the cortex [1]
- longer cell processes, hence increasing connectivity .
- greater connectivity with the rest of the brain. [1]
- new areas: subtract the components of a rat cortex from that of a primate - most of the latter unaccounted for. [19]

A significant portion of the human PFC, in the dorsolateral area, may not exist outside primates [3]. This dorsolateral PFC is the seat of 'Working Memory' [10]: the capacity for, literally, 'holding in the mind' material from anywhere else in the brain while you consciously work on it.

Comparison of brain size: rodent, cat, primate, man

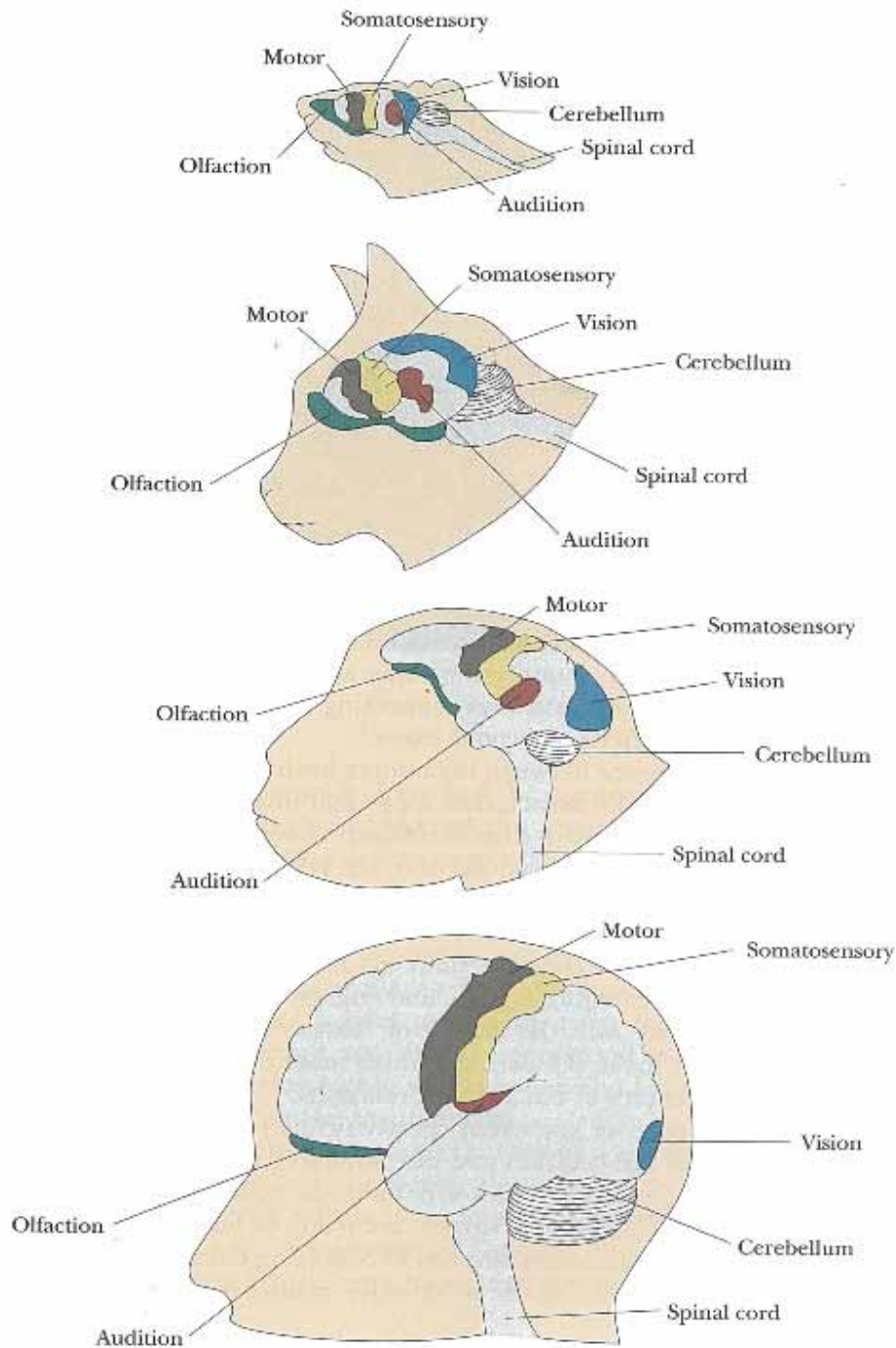


Figure from Gould and Gould (1999) published in *The animal mind*, Scientific American Library, Distributed by W.H. Freeman and Co. Basingstoke UK RG21 6XS

Note the enormous difference in size in the frontal, grey lobes between man and the other 3 species. In both the cat and rodent it is reduced to a sliver between the olfactory (green) and motor (black) portion of the brain

Changes within primates:

Monkeys to apes to us: increase in size of the cortex and its proportion given over to the PFC. [15.17]

Human specialities

Many human/monkey differences within the cortex , :

- cell types e.g. spindle cells, large, late developing, multi-connected neurons, especially rich in the right anterior insula (see part 2, section 3 on Autism) [4]
- anatomical organisation
- signaling chemicals
- distribution/ density of connections [2, 4, 17]
- more genes 'turned on' [3]
- enlargement of the 'relay station' for information between body and cortex [2]
- increase in its connections back to the PFC [3]
- Overall, greatly increased complexity in the system [1] - room for 'emergent' (i.e. totally new) properties

SUMMARY, all the above implies an "*increase by several orders of magnitude*" in cortical powers in man. Despite the claim that size is the only difference between humans and apes, it is humans who have university departments studying chimps, and not *vice versa*!

3. COMPARATIVE PSYCHOLOGY: LESS CORTEX IN ANIMALS - DOES IT MATTER?

Comparisons with human development {12, 15, 28}

Self awareness as indicated by self-recognition in mirrors.

Apes. Evidence remains controversial, even after 30 years.X [20, 21]

Monkeys. A recent recantation over data for monkeys. [11a]

The rest. 'Extensive efforts' have failed (except perhaps in dolphins, and 1 out of 3 elephants [31])

Infants. Humans manifest self-recognition by 2 years of age.

Awareness of own/others' thoughts, intentions/'mentalising' [18]

Apes. Some experts are convinced, others certainly not [13, 13a]

Other primates and the rest. No accepted evidence.

Infants. Develop this at 2 to 4 years, tell lies!

Ability to 'travel in time - Metal time travel (MTT). [14]

Chimps and monkeys. "present orientated," do not prepare [22]

The rest. Anticipation absent beyond a few minutes? Hints in birds! [27] and mice [29] (However there is dispute if it shows a primitive precursor of MTT or a quite different process involving associative learning [30].)

Infants : Anticipation, forward planning, is on-going at 2 years of age. [12]

Tasks requiring imagination or deliberate pretending:

Apes. There is *no* 'conclusive' evidence in the wild.

Other primates and the rest. No convincing observations.

Infants. They are having great fun doing this when 2 years old [12]

Tool use:

Apes. Simple examples, no evidence of adults teaching. [16]

Monkeys. Sometimes develop a tool by chance, trial and error, [23]

Infants. By two years of age, far better than adult apes.

Planning beyond requirements of current needs.

No evidence in any animal (food-storing is 'instinctive')

Picturing in the mind: e.g. see video of reward in another room, go to that room and then straight to it.

Apes: Hints of this ability have been seen in 'maximally educated' apes only.

Monkeys and 'the rest'. Either ignore pictures or treat them as real e.g. attack them!

Infants: Humans can do this by 2.5 years of age.

SUMMARY.

Mature apes, score for **human thinking**, at the level of a 2 to 4 year old child, monkeys at 1.5 years. For the rest, 'evidence comes there none'.

P.S, Neurology, Imaging and Psychology come together [26]

Imaging studies show a dorsolateral area in the PFC is activated specifically in mentalizing, which includes some of the specifically human changes (rudimentary in apes) listed above. It is noted that this agrees with mentalizing being 'rampant' in humans, 'questionable' in apes and 'absent' in monkeys. This area is specifically activated when reflecting on one's own mental states, including emotions.

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PART 2 Interoception and body-models

INTRODUCTION (Added subsequent to presentation in November 2006) What it is like to be, or as implied in the title, "not to be...." depends on consciousness, on 'knowing'. The following development in robot technology for self-repair (New Scientist 251106 p 30) may provide a helpful analogy for this otherwise elusive concept. The robot is sensitive to its bodily movements (interoception) and records them so as to form an internal model of its mode of locomotion (body-model), which is checked against software models of possible modes and the one that fits is selected - the robot now 'knows' (is conscious of) its state . e.g. it has models for movement with 2, 3, or 4 legs - in trial movements the 4 leg model fits what is happening on the ground - it 'knows' it has 4 legs. Later when it tries again the 3 leg model fits - it now 'knows' it has 3 legs active hence, given a 'memory' that at the previous test it had 4 legs, 'knows' that one is now inactive (injured): as a result it might initiate repair activity, or reset the rest of its 'behaviour' to suit tripodal motion. The operational advantage of this analogue of consciousness is obvious.

There will be a similar evolutionary advantage for an animal if it develops a model of its body state/activity which is 'looked at' by the brain (interoception) allowing centrally organised corrective action (homeostasis). Then the animal can be said in some sense, to know/be aware of, its bodily state - a basic form of consciousness as hypothesized most recently by Damasio [19] as underlying all other levels.. Anatomical systems for both elements -the body model and the connected higher brain centers which looks at it - are demonstrable in animals and can be shown to be physiologically active.

However, the level/quality of the consciousness that results will depend on the quality of both components. For the model what matters is detail and topography. Using a map as an example, how many of the objects in an area are shown and how correct are their locations. For instance, a map can show good detail, i.e. everything on the ground between two locations but have bad topography, the locations incorrectly aligned so that one sets off in the wrong direction, or have good topography, have them correctly aligned but have disastrous detail, fail to show an impassible bog between them. The level of conscious will depend on the sophistication of the components themselves and the amount and complexity of connections between them. For instance a large and 'well-connected' computer can do things a smaller, simpler version can't dream of (if it can dream at all!)

In 2002 the discussion on this site solely concerned the brain's interpreter system, the frontal lobes of the cortex, specifically the Prefrontal Cortex (PFC) and its unique development in humans. This has been reviewed in part 1. Now, in 2006, the discussion is as much about the system providing the body model/map: this is reviewed in part 2. It has been newly analysed and, as for the frontal lobes, found to be uniquely developed in humans.

The data will be presented under the same set of headings used for the live presentation. However the material has been converted from the original telegraphic style into text with references added in square brackets.

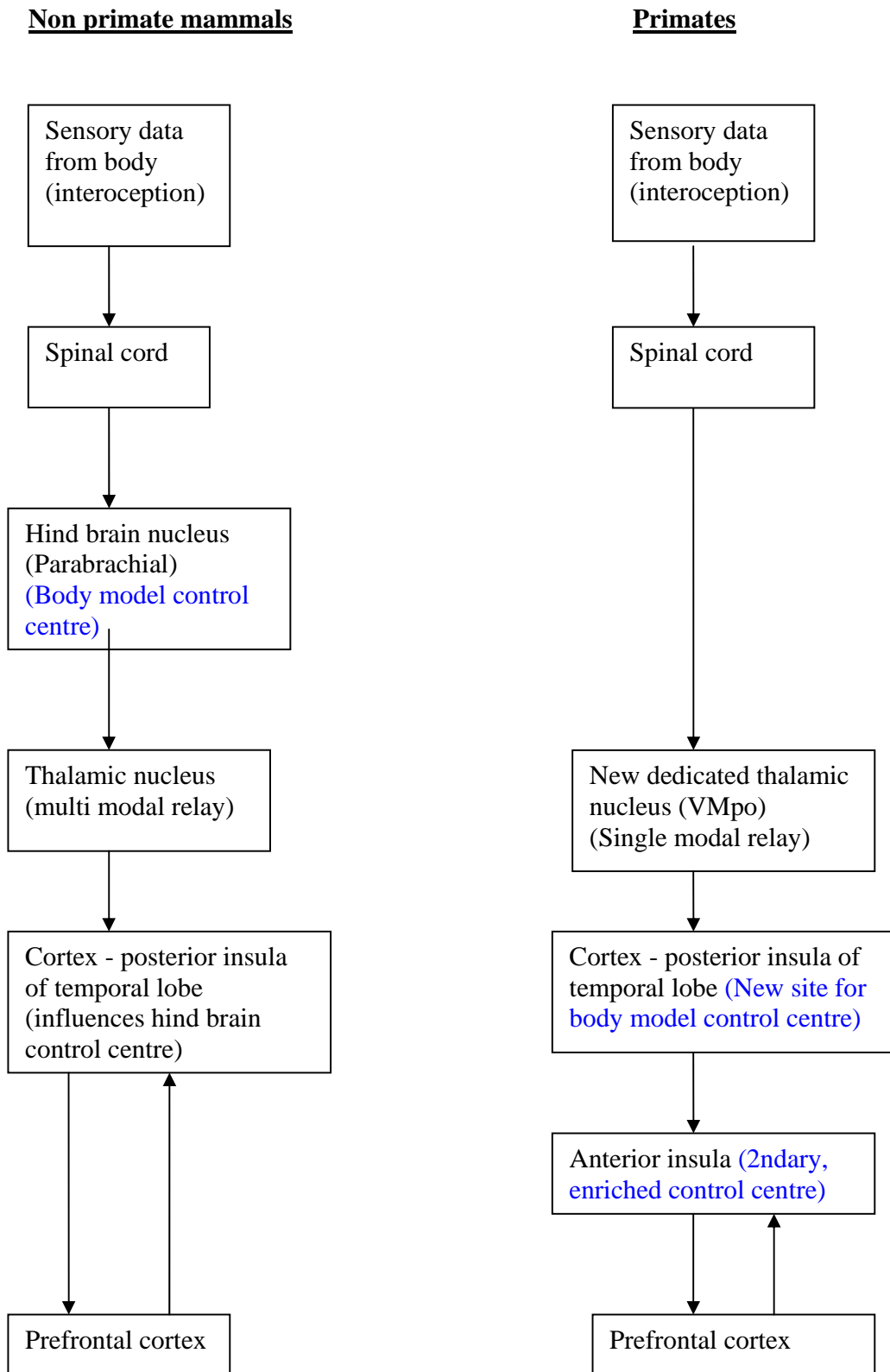
SUMMARY FOR PART 2

Since 2002, the year of the last meeting, there has been publication of new findings of considerable significance. They begin with the anatomical demonstration in humans of a

new path for the nerve tract which provides sensory information from all over the body. It by-passes the old integration site in the hind brain and runs direct to a new integration site in the cortex and replaces a multi-modal relay station with one dedicated to its own use. Thus it fast-tracks sensory information to the cortex with reduced risk of 'noise' (e.g, cross-over within a multi-purpose relay), thereby representing/modeling bodily events with increased immediacy, resolution, detail and precision, in the cortex itself. This system is rudimentary in higher primate and absent in non-primates. Such integration or 'body modelling' is held to provide the basis for consciousness and such a 'new and improved' model may have allowed, and been necessary for, progression to self-consciousness. These new findings continue with a host of neuroimaging studies supporting this idea: they show that there is further movement of activity forwards through the cortex to an FL site on one side only – N.B. lateralisation is a peculiarly human attribute. Tellingly, this is maximally active if, and only if, the subject is expressing/experiencing feelings related to themselves or is subjectively aware of their own emotional state. Moreover in identical tests, subjects who cannot do so/be so, do not show activity. Moreover, this activation can be induced in normal subjects even in the absence of any external stimulus, by the very human faculties of imagination or recall of emotional events, hypnosis or placebo-induced analgesia.

In the absence or rudimentary state of the anatomical system underlying these phenomena, subjective consciousness and introspective feelings, are likely to be greatly reduced, at the least: not only is much of the cortical apparatus for thinking as a human reduced if not lacking in other mammals, but the requisite data-base remains untransformed in an early region of the brain,

1. INTEROCEPTION AND CREATING A BODY MODEL AS FOUND IN NON PRIMATE MAMMALS, COMPARED WITH PRIMATES [From references 5 and 6]



Data from sense organs in the body travels to the brain via the spinal cord (the autonomic system): it concerns basic body parameters such as core temperature, skin temperature, water balance, salt balance, heart rate, breathing rate, energy supplies, injured tissue etc etc - the process is called interoception (working with data from inside the body: working with data from outside the body - the major player in part 1 - is termed exteroception). The interoceptive data is thus collected together/integrated in an organ in a 'primitive' brain area (parabrachial nucleus of the hind brain) to form a body model/map, which allows it to act as a control center which reflexly monitors the need for corrective action (homeostasis). The integrated data is then relayed via a multi-modal relay in the thalamic fore-brain to an area in the temporal cortex, the insula, and further to the prefrontal cortex, in particular the orbitofrontal cortex. This contains information from experience about what is rewarding or punishing (to be sought after or avoided) [15]. It can feed back to the insula which can modulate the hind brain control center in the light of such information.

As before, the interoceptive data from the body of primates travels via the spinal cord. But now it by-passes both the original hindbrain control centre and the original multi-modal relay, to land directly in the fore-brain at its own designated, new uni-modal site, the posterior ventral medial nucleus of the thalamus (VMpo) [8] Then on to the posterior insula as before and on to the PFC but NOT as before! (See 3 below) N.B. This system is described as "rudimentary" in non-human primates.

2. THE NEW PATH: CHANGES SO FAR

The primitive brain nucleus has been by-passed.

A multi-modal relay replaced by uni-modal relay

The control center and 'body-model' has moved up into cortex.

Advantages of the new path

The new relay station (VMpo) receives data direct from the body. This is significant, as data travels up the spinal cord in a remarkably detailed manner (in so called 'labeled lines' [9] - i.e. each sense organ having its own path), so a relay station can be constructed with an accurately topographical lay-out (as demonstrated by neuroanatomy and neuroimaging [10]) and with no risk of 'noise' from other activities. (Contrast this with the primitive path where the labeled-line data was transmitted after it had been integrated/merged in some way, by the primitive control center, and then via a multi-modal relay.)

Now, the new control center and then the PFC receive topographically accurate data from the new relay station. The control center itself has moved from the more primitive hind brain to the immensely sophisticated cortex with its immense capacity for exchanging information within itself and with the rest of the brain.

Results

Overall a more detailed, higher resolution, topographically correct and error-free, body model - a significant change in itself for what is held to form the basis of consciousness. However this 'new and improved' model is only the start! It has a fascinating transformation *en route* to the PFC from its primary site described here, to a secondary site, described next. .

Brain areas of *Homo sapiens*

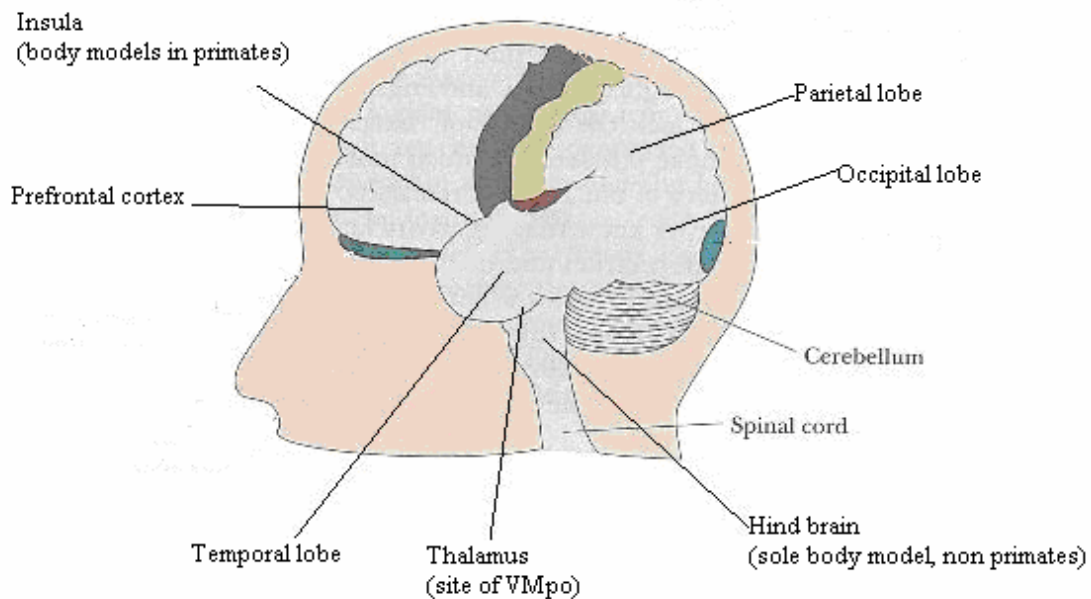


Figure adapted from Gould and Gould (1999 above)

The cerebral cortex consists of two anatomically and functionally distinct halves. The posterior half handles mainly sensory data and consists of occipital, parietal and temporal lobes: the anterior half commonly referred to as "The "frontal lobe", is concerned with movement, decision making, and all higher order processes such as imagination, concept formation, etc. Note that the prefrontal cortex (PFC) which handles these higher functions, occupies much of the anterior half of the human cortex. The insula is hidden on the inside surface of the temporal lobe.

3. THE PATH TO THE PFC: ENTER NEUROIMAGING [Main references 5 and 6]

Neuroimaging (NI) shows the activity in the modeling cortex to move through the insula from the posterior primary site (*primary model*) to come to lie in the anterior insula on one side only, forming a lateralised *secondary model* [see also 4]

Especially in humanoid primates (apes and us) the middle and anterior insula is greatly expanded and can add in to the basic interoceptive data of the primary model, a model of the outside world based on data from the other senses (exteroception) as well as emotional data - i.e. value judgments as to whether events are good/bad, threatening/promising, rewarding/punishing etc - to generate a representation of the self in the world - the secondary model - in the anterior insula [16].

A note on LATERALISATION: whatever its significance here, it is certainly something to do with making us human, (even apart from language !), because of its massive

development in humans

A note on AUTISM : in the modeling area occurs a type of neuron (spindle cells) almost 'unique' to humans (a few in apes) These show a reduced frequency in severe autistics which is in proportion to with these individuals reduced NI activity in the secondary model, suggesting that they contribute significantly to its functioning [2].

Overall the human PFC would seem to work with a model of a higher quality than in apes, who have few spindle cells , but certainly more so than in monkeys which lack those cells and whose posterior and mid-insula remain relatively undeveloped , and immeasurably more so than in non-primates which lack the new path *in toto*.

But under what conditions is this lateralised, forward-located secondary model maximally active?

4. WHEN DOES THE SECONDARY MODEL LIGHT UP?

In short when there is subjective feeling/attention to self. This was first demonstrated for pain and subsequently with heat, touch and other interoceptive senses. Pain provides a particularly clear picture [7] as follows.

Experimental shocks of varying intensities were given to a subject's hand:

In the posterior insula i.e the primary model, activity correlated with voltage ranking

In the anterior insula i.e the secondary model - the correlation was different. It was with the subjective ranking

Thus the secondary model reflected perceived/subjective intensity not the physical intensity.

Furthermore, there are situations where subjective activity/input can modulate perceived pain - placebo analgesia [3] and attention-diversion analgesia [cited in 5 6 and 14]: under these conditions, secondary model activity is decreased.

Perhaps even more striking evidence for the relation of secondary model activity to subjective feelings comes from its activation when subjective pain is induced in the absence of a stimulus [cited in 5 6 and 14], i.e by hypnosis,

.
The tail creates the dog!

Neuroimaging scans in Man

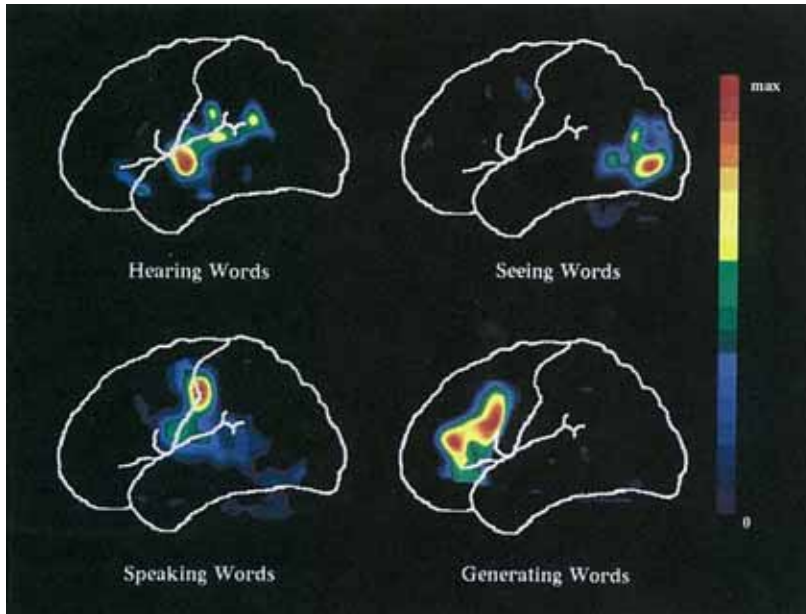


Figure taken from Gould and Gould 1999

Series of neuroimaging scans taken during four different thought processes in Man. Similar scans are not obtainable in non primates.

5. SECONDARY MODEL ACTIVITY IN MORE COMPLEX TASKS

A number of studies have examined secondary model activity in subjective situations of greater complexity than direct perception of sensory stimuli. One set employed tasks with or without a 'self' involvement, for example:

Consider WHAT do YOU think of X - Just think of X, e.g. a city

The secondary model showed greater activation in the first of the two, i.e. the personal task

Other sets of tasks distinguished between *having an emotional experience and attending/interospecting to that emotional experience*. [Cited in 12] For instance, on viewing an emotionally charged picture, one task was to report if it is indoors or outdoors, in the other, it was to tell of the emotion aroused. Again secondary area activity was increased in the latter, the personal task.

Reference 6 cites a wide variety of NI studies showing secondary area activity correlating with the level of response during subjective emotions, including anticipatory anxiety, disgust (at facial expressions), trustworthiness (of faces).

"A landmark result" [17 as cited in 6] indicates that the secondary model also underlies awareness of the subject's feelings for the feelings of others - empathy: its activity increases when observing discomfort of subjects with whom you are emotionally

involved.

Notably, empathy is absent in severe autistics who (as noted previously) lack the human specialisation of spindle cells in the insula and show less activation in relevant situations.

To move to a still more complex level of subjectivity, the model is activated in some peculiarly human emotional attributes:

Recalled emotional moments: [13]. (N.B. the analogy to hypnosis-induced pain i.e. the feelings occurring absence of the external stimulus)

Musical appreciation: recognition of discords is shown by even preverbal infants but not by monkeys. This and other findings have led to the following judgment: *There is evidence for innate musical preferences in human infants, preferences that do not seem to be shared by our primate relatives* [18]. Here then is evidence that the secondary model is essential for attributes which are unique to humans.

6. THE SECONDARY MODEL SENSES (DETERMINES?) INDIVIDUAL DIFFERENCES

Secondary model activity reflects not just types of responses but level/accuracy of an individual's introspection: this implies a tight relationship with subjectivity.

One study tested this by requiring subjects to distinguish between synchrony/asynchrony of an external signal with their own heart beat. Activity in the model correlated with their accuracy of performance.

In the same study, levels of bodily awareness were assessed by psychological testing and the absolute size of the modeling-area assessed by non-invasive morphometry. Size correlated with awareness level. . (Could this be termed the "Sensitive Plant" effect after the clearly introspective poem of the same name by the hypersensitive Shelley?)

Finally there are individuals who do not manifest a subjective response where it would be normal to do so; these individuals do not activate the secondary model. 1. Autistics have already been mentioned, with their defective awareness of other's feelings - in addition to reduced model activity, severe examples show a reduction in size of the modeling-area.

2. Subjects with pathology or injury in the modeling area - when pain may be less significant, music no longer appreciated.

3. Subjects with defects in the body-state system signaling itself (autonomic defect). It is of particular interest that emotional feelings are also much reduced in these individuals. This provides particularly pointed evidence that awareness of bodily responses is required for emotional feelings, just as originally suggested by William James in the C19 (What a pair he and his heavyweight novelist brother Henry must have been at a James' family gathering!)

7. EVIDENCE OF ABSENCE IN NON PRIMATES

So far the contention that non-primates, at least, will possess a type of awareness that differs from that in humans, has been inferred negatively (by the absence of the human system) from neuroanatomy. To quote from reference 6:

"The emotional behaviour of non-primate mammals suggests the anthropomorphic

inference that experience feelings from the body in the same way that we do. However the neuroanatomical evidence indicates that they cannot, because the phylogenetically new pathway that conveys primary homeostatic afferent activity to the thalamus and cortex is rudimentary or absent."

However there is also positive evidence for the absence of the new system in non-primates. Cats were trained to behaviourally "finely discriminate" - i.e. to rank - the intensity of thermal stimuli ("cat on hot bricks" experiment?). Lesions were made anterior to the hind brain control center, which would interrupt the new path were it present but not the old - their behaviour was only weakly and transiently disrupted. Lesions below the control center (i.e. of the old path) disrupted behaviour completely and permanently. In Humans damage anterior to the old center, not only removes feelings, but disturbs behavioural responses to bodily needs (homeostatic motivations) showing that the control center has indeed moved forward [6].

8. SUMMARY OF WHAT IS CHANGED WITH WHAT RESULTS

There is a new path from periphery to brain resulting in a topographically organised primary model in the cortex.

This higher quality primary model is able to generate a secondary model which is associated with (necessary for?) self awareness /subjective feelings.

The secondary model can even be formed in absence of an external stimulus: thus there is now a mechanism for mental activity to be 'decoupled' from ongoing stimuli, from the present [14]. Such ability is clearly necessary for mental time travel, imagination, "day dreaming", and reflective consciousness.

Without this ability to 'decouple', to escape from the tyranny of the moment, it is hard to believe that there can be any sense of an individual self to whom things happened in past and might happen in the future and therefore, a self to whom things are happening at the present.

Without such a sense of self it is hard to believe that there can be understanding of others as 'selves' with their own set of feelings, beliefs, intentions etc.

These assumptions, based on neuroanatomy and neuroimaging are in complete agreement with findings of comparative psychology that these attributes are uncertain or absent in all but humans (discussed in part 1).

Thus two approaches give the same answer, always encouraging in science!

9. HUMANS AND OTHER MAMMALS

The basic system for consciousness in all mammals consists of:

1. interoceptive data from the body organised to form a body model or map and
2. an interpreter and modulator, the FLs.

In humans this system is hugely extended so that the primary body model provides a secondary model enriched by external and emotional data, for interpretation by the PFC. However there are also significant changes in the two basic components of the human system.

The primary model is now cortical, and has its own delivery system providing unmodified data. The area anterior to the model is greatly expanded, presumably a *sine qua non* for the model's enrichment by sensory data from other brain areas during its

passage to form the anterior secondary model [22 and see note]. The latter is anatomically distinct and lateralised

The interpreter, the PFC, has been hugely 'updated'. In particular the subdivision directly fed by the secondary model (the orbitofrontal cortex) is greatly enlarged [15] while, perhaps of even more significance, a new subdivision (the dorsolateral cortex) is added [20] - if any area can be designated 'the thinking bit' of the brain, it is this, the seat of 'working memory' [21], where everything in the brain can be brought together to create conscious human thought.

In humans then, a vastly developed model is interacting with a vastly developed PFC. As in any system which consists of interconnected component, increasing the power of all components at once will lead to an increase in overall output which is greater than the increase in the power of any single components. Remembering that the output in this system is nothing less than consciousness, humans must have their own level of consciousness with unique properties, or science counts for nothing!

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Note: This paper by Frith makes the case (very readably!) for the most recent thinking that the brain constructs a model of the outside world from incoming data (just as discussed above, it does from internal data for the inside world i.e. the body). It is this that we perceive, not the external phenomena themselves. (Some evidence for this is the existence of optical illusions - the model we perceive and consider as reality, occasionally is constructed in a way that does not fit the real reality). Thus full human subjective consciousness emerges from the combination of two models in the brain, one of the body, the other of the world outside, which having been worked on by the brain during their construction, are brought together to form the secondary model and then worked on all over again!. No wonder it is proving so difficult to pin down exactly why it is humans who have university departments studying chimps and not *vice versa*.