

**Topic and Essay: How and why is the human brain different?**

The human species is psychologically and behaviourally unique. At the level of behavioural ecology, humans are a special species simply by not being confined to a single ecological niche (Bingham, 1999). Beyond that there is a widespread consensus that the human species has unusual psychological capacities, even though there are wide differences in how these should be described or defined.

Assuming unique psychological capacities of some kind, the neuropsychological question is then how these depend on special characteristics of the human brain (see e.g. Deacon, 1997a&b). Broadly speaking, the main answer to this question is “we don’t know”, but there is a range of attempted answers which are worth exploring.

**Why?**

The why? and how? questions are in fact difficult to separate, but the standard answer to why? would be because human evolution has made the human brain different (Bradshaw, 1997; Moll et al., 2005). There is general agreement that: the common ancestor of modern humans and modern chimpanzees occurred about 5 or 6 million years ago; bi-pedalism preceded brain expansion and tool use, and probably goes back 3.5 or 4 million years; early tool use goes back at least 2 million years and extensive tool use was typical of *homo erectus* for more than a million years before the oldest (“archaic”) fossils of *homo sapiens* are found; the use of fire by *homo erectus* was also well-established; during the 5 million years since the common ancestor of humans and chimpanzees brain size in the human line has increased, from little more than modern chimpanzee size (which is about 350 cc) in the first bipedal hominids, to 2-3 times this size in *homo erectus* to and 3-4 times as big a chimpanzee brain in modern humans.

**Brain-size**

This gives one simple answer to the how? question: the human brain is outstandingly big, given our body size. However it is clearly not the whole answer, since relating brain-size to body weight is complicated (Deacon, 1997b) and the human gain in behavioural terms is more extensive than would be predicted on size alone. Genes which may be responsible for primate and human brain expansion are currently being investigated (Ponting & Jackson, 2005; Evans et al., 2006; Pollard et al, 2006; Sikela, 2006; Tang, 2006)

**Lateralization**

One additional factor is lateralization. Although there are some who suspect that human brain lateralization is a development of primate asymmetries (Corballis, 2003), the data on population handedness suggests a fairly sharp distinction between the degree of handedness observed in other primate populations (zero according to the meta-analysis by Papademetriou et al., 2005) and the human figure of 90% right handedness, which does not correlate completely with language lateralization, but which may be related to it. The functional lateralization is not always predicable from brain measurements, but new techniques (Buchel et al., 2004; Hutsler, 2003, Sun & Watson, 2006; Sun et al., 2006; Luders et al., 2006) and theoretical models (Monaghan & Shillcock, 2004) may strengthen the link between physical lateralization and human specializations.

**Brain re-organization: expansion of the frontal lobes**

Apart from lateralization, other kinds of re-organization with-in the brain might have been possible within the time-scale of human evolution. The most popular hypothesis for many decades has been that the human frontal lobes, presumed to be the main site for planning and self-control, have either generally expanded or undergone some more detailed change (Deacon, 1997a&b; Schoenemann et al., 2005).

However, MRI scanning of different great apes and comparison with human scans has led to the conclusion that there has been no disproportionate expansion of the human frontal lobes --- they are bigger than those of a chimpanzee, but only because the whole brain is bigger (Semendeferi and Damasio, 2000; Semendeferi et al., 2002). Schoenemann et al.(2005) recently suggested that prefrontal white matter is disproportionately larger in humans than in other primates, but Sherwood et al. (2005) countered that although the data showed humans having more white matter than the average primate, they did **not** show a difference between humans and great apes. Preuss (2004) suggests that what has happened is that, while the primary motor and sensory areas in the human brain are roughly the same size as those in apes, secondary areas (“association cortex”) has greatly expanded in **all** the lobes of the human brain. Others have suggested that certain neuronal features of primate and human frontal lobes hold the key to understanding human intelligence: pyramidal cells in prefrontal cortex (Eltson et al., 2006) or certain spindle cells in anterior cingulate and fronto-insular cortex (Allman et al. 2005).

There still remains the difficulty that superficially the human brain is more similar to that of a chimpanzee than we might expect by comparing the behaviours of the two species. Thomas Huxley, a champion of Darwin’s put it this way in a supplement to Darwin’s book *The Descent of Man* —

“So far as cerebral structure goes therefore, it is clear that man differs less from the Chimpanzee or the Orang, than these do even from the monkeys, and that the difference between the brains of the Chimpanzee and of Man is almost insignificant, when compared with that between the Chimpanzee brain and that of a Lemur. “(Darwin, 1871/1901, p. 312)

also —

Every principal gyrus and sulcus of a chimpanzee’s brain is clearly represented in that of a man’

The second claim is probably misleading, since the reverse is certainly not true, and it may be that the 21st century conclusion is radically different, when more is known about the genetics of the difference between human and chimpanzee brains (Culotta, 2005). The initial sequence of the chimpanzee genome was published last September ( Mikkelsen et al., 2005) and it is highly likely that greater knowledge of genetics will emphasize differences rather than similarities. Caceres et al. (2003) applied a variety of genetic techniques to the cortical tissue (removed post-mortem) of humans, chimpanzees and rhesus macaques. These suggested that humans and chimpanzees are more similar to each other than to the macaques, which is as expected, but also that there were dozens of genes that were expressed very differently in human and chimpanzee cortex, with 90% of these being expressed more actively in humans than in chimpanzees, which suggested that the human brain is characterized by “elevated levels of neuronal activity”. As a contrast, comparing gene expressing in the human and chimpanzee heart and liver revealed very little difference of this kind. However, Sherwood et al., (2006) suggest that a higher metabolic rates is simple a consequence of the brain size increase.

A minor confirmation by genetic analyses is that the human sense of smell is reduced by comparison to the chimpanzee, and that both humans and chimpanzees have less sense of smell than dogs or mice. This can be done by counting olfactory receptor genes and the proportion of these which are inactive (pseudogenes). Humans have a significantly higher proportion of these than chimpanzees (Gilad et al., 2005). Although further detailed distinctive features of the human brain may be expected, it is also the case that there are some features of the human brain, in particular the organization of the visual system, where the details in the human brain differ very little from those in chimpanzees (e.g. Cola et al., 2005)

### **Functional differences: language**

Apart from looking at neurophysiological or genetic details, it is possible to give hypothetical answers to both the how? and why? questions by making assumptions about the new psychological capacities subserved by human brain evolution, for example “The origin of humans was accompanied by the emergence of new behavioural and cognitive functions, including language and specialized forms of abstract representation.” (Caceres et al., 2003). The two most frequently appealed to candidates for

new psychological capacities are language and an enhanced capacity for social cognition. Language remains a strong candidate for a human specialization because chimpanzee abilities appear to be so limited (see weeks 10 and 11 course P207). There are however several very different suggestions as to how this human specialization arose.

*i) Recursion.*

Hauser et al. (2002) for instance, although considering other possibilities, favour the notion that recursion is the key uniquely human component of language, but paradoxically from a Darwinian point of view, they argue that recursion probably evolved “for reasons other than language”. Recursion is illustrated by Chomsky’s well-known sentence “colourless green ideas furiously sleep”, which we understand as a grammatically correct sentence even though it makes little sense. The sequence “I will say a very, very long sentence”; “I will say a very, very, very long sentence” and so on is a simpler illustration that a principle for combining just a few words can generate an infinite number of possible utterances. Hauser et al. (2002) recognize that language competence also requires specialized sensory and motor machinery for speaking and decoding speech, and conceptual and intentional aspects of communication via language, but suggest that these aspects of language competence have a long evolutionary history and are shared with other species.

*ii) Darwinian evolution of all parts of the human language system*

The Hauser et al. (2002) suggestion tends to minimize the role of human evolution because a large part of the language system is held to be shared with other species, while the uniquely human part, recursion, they would prefer not to be an adaptation (i.e. not evolved by Darwinian selection).

Pinker and Jakendoff (2005) supply a lengthy argument against the Hauser et al. (2002) position, since they had both previously put forward the position that human language is “a system of co-adapted traits that evolved by natural selection” for the purpose of communicating ideas (“complex propositions: Pinker and Jakendoff, 2005; p. 204; see e.g. Pinker and Bloom, 1990). They believe that the capacity of the human brain to handle recursion evolved by natural selection, but that many other aspects of brain capacity necessary for language, particularly for conceptual structure, speech perception and speech production, needed to be shaped by natural selection as well.

Pinker and Jakendoff (2005) are also able to appeal to genetic evidence that was not available 5 years ago. Although there are disagreements as to exactly how the evidence should be interpreted, it is now the case that at least one gene (FOXP2: there are expected to be many others, Fisher et al., 2003; Fischer, 2006; Ramus, 2006) has been identified which has some effects on language related skills, and which appears to have undergone evolutionary change which makes the human version different from that of the chimpanzee (Enard et al., 2002). Its discovery resulted from the study of a members of a family suffering from a rare speech disorder characterized by difficulties in making complex orofacial movements, with profound deficits in articulation, but also deficits in other language skills including comprehension. Pinker and Jakendoff (p. 218) are able to make the point that “The possibility that the affected people are impaired only in recursion is a non-starter.” Instead the expression pattern of FOXP2 in both mice and humans suggests that it is involved in the development of circuits for motor control necessary in vocalization (Lai et al., 2003; Shu et al., 2005). The fact that there are homologies between humans and mice in this respect could be taken to support Hauser et al.’s point about some aspects of human language having a long evolutionary history, but the more conventional Darwinian position would be to say that motor control for vocalization has a long evolutionary history, but that the uniquely human capacity for speech will have necessitated special brain mechanisms for the co-ordination of articulatory organs which are not shared with other species.

*iii) Emergence of language from a number of “language ingredients”*

Elman (1999, 2005) provides yet another account of language, which is Darwinian in that it emphasises that “species-specific biological factors play a critical role in the ability of humans to acquire and process language (1999, p. 1) but which differs from the account given by Pinker in predicting a lack of any genetic control of specific cortical micro-circuitry for language. Instead

language “is simply the result of a number of tweaks and twiddles” which produce changes in human in such things as vocal tract control, sociality, imitation and shared attention. These traits then interact to produce the unique human capacity for language. Although this account comes from the connectionist tradition and the “emergentist” aspect leads to the expectation that there will be complex developmental trajectories, “tweaks and twiddles” are entirely consistent with Darwinian processes, and changes in vocal tract control presumably would need to be brought about by something like changes to FOXP2.

### **Functional differences: social cognition and theory of mind**

An alternative function role for the large brains of primates has been suggested to be social cognition (Jolly 1966; Humphrey, 1976; Barrett & Henzi, 2005; Allman et al., 2005). This has the advantage of applying to the large brains of non-human primates, as well as, putatively, to humans, but the disadvantage that it does not by itself explain human tool using, although the social transmission of tool using skills may have been a crucial component of the success of this strategy.

Current work on social cognition includes evidence that chimpanzees and other great apes appear to have skills which might be regarded as precursors to a theory of mind, for instance the ability to understand both human (Call et al., 2004) and conspecific (Tomasello et al., 2003) psychological states, but also points to the severe limitations of chimpanzees’ social cognition by comparison with the human case. In particular, chimpanzees can show understanding of what a conspecific has or has not seen when competing for contested food, but the often “show surprisingly weak social-cognitive skills” in tasks which require social co-operation (Hare & Tomasello, 2004; Warneken et al., 2006; Warneken & Tomasello, 2006).

### **Functional differences: cultural learning and invention**

Tomasello & Rakoczy (2003) have argued that there are two (initial) stages of uniquely human social cognition. The first stage is observable in one year olds, who have an understanding of other persons as intentional agents, which enables them to take part in pretend play, and is important as a prerequisite for shared attention and early social and linguistic learning. The second stage is the “Theory of Mind” belief-desire psychology which normally starts around 4 years of age, but which is dependent on several years of linguistic communication. These early stages of uniquely human social cognition form the basis enable the “cultural ratchet” of social and technological innovation (Tomasello et al., 2005;).

### **Conclusion**

There is of course no reason to have to choose between language and social cognition as the drivers of human uniqueness, since language has social functions (Dunbar, 1993) and Bloom (2000) suggested that theory of mind capacities lie behind what happens when children learn the meaning words. But in both cases the functional differences are at present better understood than the neurophysiological details of the special features of the human brain which cause the functional differences.

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Von Economo neurons (VENs) are a recently evolved cell type which may be involved in the fast intuitive assessment of complex situations. As such, they could be part of the circuitry supporting human social networks. We propose that the VENs relay an output of fronto-insular and anterior cingulate cortex to the parts of frontal and temporal cortex associated with theory-of-mind, where fast intuitions are melded with slower, deliberative judgments. The VENs emerge mainly after birth and increase in number until age 4 yrs. We propose that in autism spectrum disorders the VENs fail to develop normally, and that this failure might be partially responsible for the associated social disabilities that result from faulty intuition.

Elston, G. N., Benavides-Piccione, R., Elston, A., Zietsch, B., Defelipe, J., Manger, P., et al. (2006). Specializations of the granular prefrontal cortex of primates: Implications for cognitive processing. *Anatomical Record Part a-Discoveries in Molecular Cellular and Evolutionary Biology*, 288A(1), 26-35.

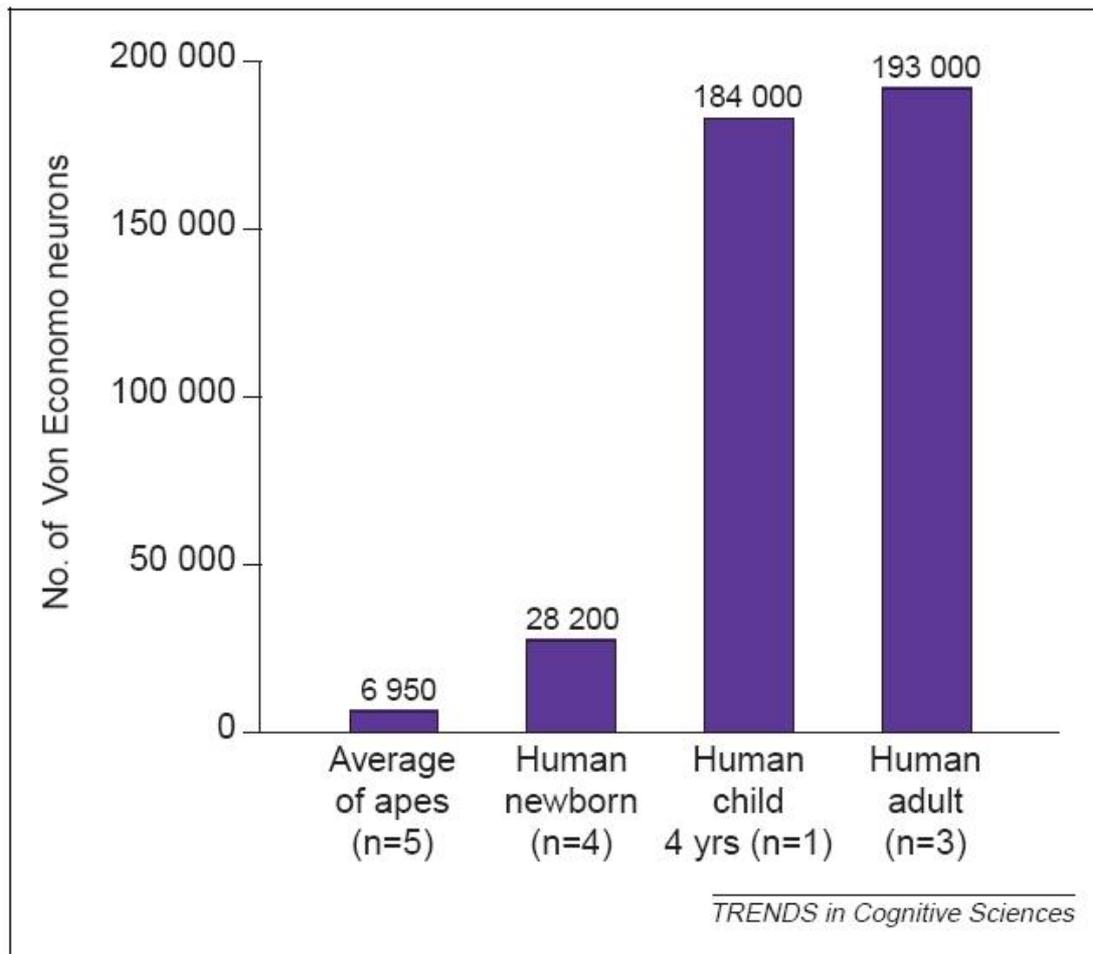
The biological underpinnings of human intelligence remain enigmatic. There remains the greatest confusion and controversy regarding mechanisms that enable humans to conceptualize, plan, and prioritize, and why they are set apart from other animals in their cognitive abilities. Here we demonstrate that the basic neuronal building block of the cerebral cortex, the pyramidal cell, is characterized by marked differences in structure among primate species. Moreover, comparison of the complexity of neuron structure with the size of the cortical area/region in which the cells are located revealed that trends in the granular prefrontal cortex (gPFC) were dramatically different to those in visual cortex. More specifically, pyramidal cells in the gPFC of humans had a disproportionately high number of spines. .... cortical circuits composed of neurons with distinguishable morphologies will likely be characterized by different functional capabilities. ....In particular, the highly branched, spinous neurons in the human gPFC may be a key component of human intelligence. (C) 2005 Wiley-Liss, Inc.

Ramus, F. (2006). Genes, brain, and cognition: A roadmap for the cognitive scientist. *Cognition*, 101(2), 247-269.

This paper reviews current progress in genetics in relation to the understanding of human cognition. It is argued that genetics occupies a prominent place in the future of cognitive science, and that cognitive scientists should play an active role in the process. Recent research in genetics and developmental neuroscience is reviewed and argued to provide a new perspective on the timeless questions of innateness and modularity. The special case of the genetic bases of language is further discussed, with the study of developmental dyslexia as an exemplary entry point. This Special Issue puts together articles providing different empirical examples and theoretical perspectives on how the integration between the different levels of description (gene, brain, and cognition) is to be achieved. (c) 2006 Elsevier B.V. All rights reserved.

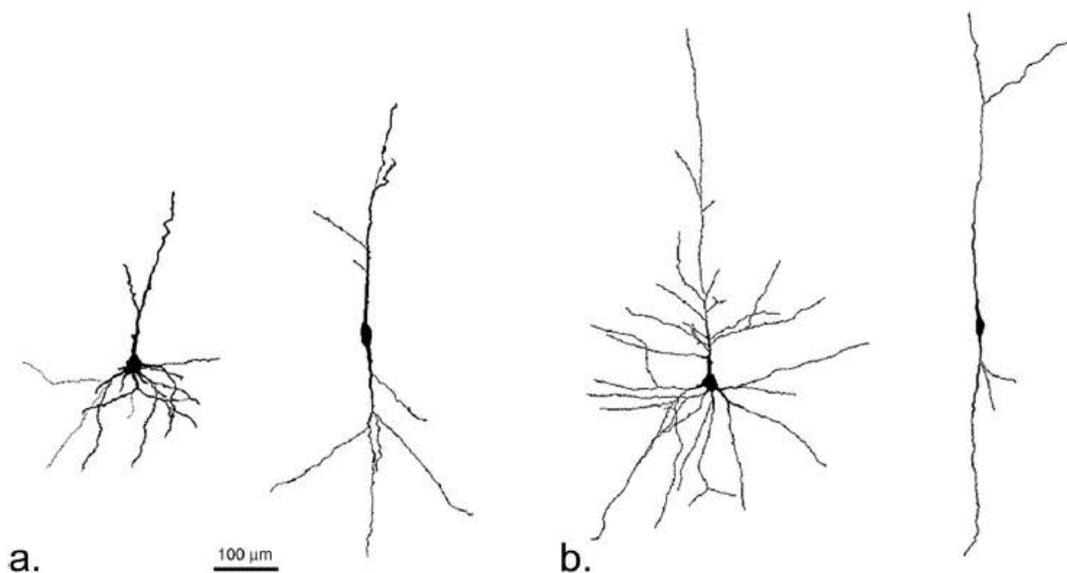
Sikela, J. M. (2006). The jewels of our genome: The search for the genomic changes underlying the evolutionarily unique capacities of the human brain. *Plos Genetics*, 2(5), 646-655.

The recent publication of the initial sequence and analysis of the chimp genome allows us, for the first time, to compare our genome with that of our closest living evolutionary relative. With more primate genome sequences being pursued, and with other genome-wide, cross-species comparative techniques emerging, we are entering an era in which we will be able to carry out genomic comparisons of unprecedented scope and detail. These studies should yield a bounty of new insights about the genes and genomic features that are unique to our species as well as those that are unique to other primate lineages, and may begin to causally link some of these to lineage-specific phenotypic characteristics. The most intriguing potential of these new approaches will be in the area of evolutionary neurogenomics and in the possibility that the key human lineage-specific (HLS) genomic changes that underlie the evolution of the human brain will be identified. Such new knowledge should provide fresh insights into neuronal development and higher cognitive function and dysfunction, and may possibly uncover biological mechanisms for information storage, analysis, and retrieval never previously seen.



**Figure 2.** Comparison of Von Economo neuron numbers. Total number of VENs in FI (total of right and left hemispheres) is shown for apes, human neonates, a four-year-old child, and an adult human. The number of subjects is given in parentheses. The data are stereological counts by the authors on brains in the Yakovlev Collection at the National Museum of Health and Science and the Semendeferi Collection at the University of California, San Diego.

(from Allman et al., 2005)



**Fig. 4.** NeuroLucida tracings of pyramidal (left) and von Economo (right) neurons from FI (a) and ACC (b). Notice the vertical symmetry and relative sparseness of the VEN dendritic tree. Neurons are oriented so the pial surface is at the top.

From Watson et al., 2006