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What is the neural substrate for the overwhelmingly superior capabilities of man?

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ABSTRACT

The capabilities of man are many orders of magnitude greater than those of animals, including primates. On the other hand, each of the neural substrates originally suggested to account for this (e.g. number of neurons, synapses, their density, etc.) have been found to be of the same order of magnitude across animals, including mammals, and even primates. A neurological explanation for the overwhelmingly superior capabilities of man is therefore not presently in hand, and further research is required.

KEYWORDS: cognition, intelligence, dexterity, neurons, synapses, cortex, brain, primates.

INTRODUCTION

It is generally agreed that the brain, especially the cortex, is the organ responsible for the cognitive capabilities of animals, including humans. Therefore a prerequisite for a study of the potential anatomical substrates for the intellectual capabilities of humans compared to those in animals is the need for a quantitative measure of intellectual ability which would be applicable to animals as well as humans. With respect to humans, one can use the Intelligence Quotient or other psycho-metric measures, but these are not readily adaptable to animals.

Manual & verbal dexterity

Perhaps, instead of such broad measures of overall intelligence, it would be simpler to assess and compare "dexterity", for example that which is involved in writing (manual dexterity) and speaking (verbal dexterity) a language. However, even this measure would also place humans many orders of magnitude above animals, including mammals, and even primates. No other animal uses language which can be spoken, written and comprehended when it is heard, communicated orally (speech) or visually (in written form). There are even many of us who can read and write several languages interchangeably, each written with different characters (script), e.g. Arabic, Chinese, Latin, Russian and Greek, written from left to right, right to left or vertically. These abilities involve manual dexterity for fine motor control, together with visual and proprioceptive feedback necessary for correctly writing a language. Rudimentary tool fabrication and use has been reported in primates, requiring some degree of manual dexterity, though not even approaching that of humans (reviewed in Roth & Dicke, 2012) [1]. In addition, speaking a language also requires auditory and proprioceptive feedback for the control of the proper shaping of the speech organs (e.g. vocal cords, tongue, teeth, lips, palate) during vowel and consonant production, which together can be called "verbal dexterity".

Properties of the brain

The search for the anatomical and physiological properties of the brain which may be responsible for such capabilities across animals should consider parameters such as the overall number of neurons, the number of neurons in the cortex, their density (number of neurons per mm^3 of brain tissue), the number and density of synapses, the number of synaptic inputs onto a neuron, axonal length, etc.

Number of neurons

It has long been thought that a larger body mass would require a larger number of neurons to control the functions of a larger body. Accordingly, many have reported a correlation between brain weight (assumed to reflect the number of neurons in the brain) and body weight across animal species (e.g. Roth & Dicke, 2005) [2]. However, in order to provide a tentative explanation for the higher cognitive abilities of man, it had been assumed that the human brain is much larger, and contains many more neurons (computational units) than a typical mammal of its size. This explanation has been challenged based on the results of newer techniques [3] which provide the quantitative determination of the number of neuronal and nonneuronal (glial) cells more accurately in the brain. Using this new method, it was found that the number of neurons in the human brain is similar to the number of nonneuronal cells, and the ratio of neurons to nonneuronal (glial) cells is similar to that found in other primates. Thus humans do not stand out over primates with respect to brain composition [4]. Therefore, as a result of the preliminary understanding that there may not be a direct relation between parameters of brain anatomy and intelligence across animals including humans, others have suggested estimating the number of "extra" neurons, or "encephalization quotient" [5], i.e. the number of additional neurons in the brain beyond those required for the maintenance of the motor, sensory and autonomic functions of the larger body size. Some have suggested that a greater number of cortical neurons, especially those in the frontal cortex, with high neuronal density, coupled with shorter interneuronal distance and high axonal conduction velocity lead together to a greater information processing capacity, thus providing higher intelligence [6]. However, the density of cortical neurons in the mouse (140,000 per mm^3) is greater than that in man (105,000 per mm^3) [7]. Furthermore, shorter processing time may not necessarily contribute to higher intelligence.

Neurons, synapses & their density

Even though it has been assumed that animals with larger brains are more intelligent, the weight of the brain in elephants (4200 g) and whales (2600-9000 g) is greater than that of the human brain (1250-1450 g) [6]. The number of cortical neurons in man (11,500 million) is the same order of magnitude as that in whales, dolphin and chimpanzee (600 million-11000 million) [2]. The encephalization quotient of man (7.4-7.8) is also the same order of magnitude as that in the animals above, as well as in monkey, cat and dog (1.0 to 2.7) [2]. The density of cortical neurons (packing density) in humans (10.5 thousand per mm^3) is similar to that in whales (6.8 thousand per mm^3), while that in rat and mouse is about 120 thousand per mm^3 [7] (summarized in Abeles, 1991) [8], i.e. even greater than that in man! In fact, neuronal density increases with decreasing brain weight, and this relation has been taken as an 'indication that intelligence does not bear a simple relation to neuron density and degree of axo-dendritic complexity in the cerebral cortex' [7]. Synaptic density in man has been estimated to be 1.0 x $10^9/mm^3$, while that in mouse is 0.7 x $10^9/mm^3$ (various sources; summarized in Abeles, 1991) [8]. It has been estimated that there are 8,000 to 40,000 synapses onto a neuron in mammals [8].

Given that the mouse cortex contains 4 million neurons, and the human cortex 11,500 million neurons [2], what can possibly be learned from a study of human-like behaviors (e.g. memory, rationality, consciousness) in lower animals such as C. elegans (which has 302 neurons) and Aplysia (which has about 18,000 neurons)!!

In final analysis, each of the anatomical measures of the brain which could be considered to be the basis for the superior intelligence of man compared to animals (e.g. number of neurons, their density, number of non-neuronal cells, number of synapses and their density, number of input synapses onto a neuron, etc.) are all of the same order of magnitude. This is the rationale for presenting a table of "average" values for the composition of cortical tissue across mammals [8]. On the other hand, the capabilities of humans are by far many many orders of magnitude greater than those of other mammals, including primates.

CONCLUSION

A *biological* explanation for the question posed in the title concerning the neural substrate for the overwhelmingly superior capabilities of man compared to other animals including primates, is not presently in hand, and much further research is required to elucidate this intriguing quandary.

CONFLICT OF INTEREST STATEMENT

There are no conflicts of interest.

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