HOW WILL BRAIN LOOK IN 1000 YEARS?

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Hypothesis
The purpose of the research article is to envisage the pattern of evolution of the human brain in the forthcoming 1000 years. The changes observed in the evolution till date were integrated with current work in the area and futuristic technological ideas to give an idea of the same, while keeping in mind the physical and biological constraints. Evolutionary factors suggest small theoretical growth of brain size for better efficiency, although recent studies conclude *dietary, environmental, and social factors* might lead to shrinkage of brain and its capabilities as we witnessed in the last few millennia. Environmental impact will play a crucial role in the development of the brain although thermodynamic limitations of the human body and feasible neurological limits of the brain sets an upper bound for growth. Evolution processes of communication and anatomy of the human body will influence the mechanism of brain evolution. However, recent patterns of brain size reduction and efficiency limitations might be reversed with the incorporation of genetic engineering in the area. *Brain-machine interface (BMIs)* would prove to be a key domain in shaping up the future of *H. Sapiens* and the proportion of integration in human lives could well determine evolution of newer species such as *H. cyberneticus* or *H. hybridus*. However, it is to be noted that these ameliorations would take place for a small section of fraternity only and decline in mental abilities and brain shrinkage would imply that a major part of society would survive on the back of the technology-assisted faction.

***Index Terms*—** Neocortical wiring, Genetic Engineering, Brain-Machine Interface, Homo cyberneticus

I. EVOLUTION OF HUMAN BRAIN

Across nearly seven million years, the human brain has tripled in size, with most of this growth occurring in the past two million years. Archeologists have noted how the volume, shape, and the relative sizes of major cerebral areas of the brain has changed over the millennia. The species of the famous Lucy fossil (3.2 million years ago), *Australopithecus afarensis*, had skulls with internal volumes of between 400 and 550 milliliters, whereas chimpanzee skulls hold around 400 ml. By this time the brains had already started to show subtle changes in structure and shape as compared with apes. The neocortex, an area of the human brain involved in making judgements and decisions, had begun to expand, reorganizing its functions away from visual processing toward other regions of the brain which indicated a shift to higher cognitive abilities. *Homo habilis* (dated 1.9 million years ago) saw a modest increase in brain size, including an expansion of a language-connected part of the frontal lobe called Broca's area. The first fossil skulls of *Homo erectus* (1.8 million years ago) possessed brains averaging a bit larger than 600 ml, whereas early *Homo sapiens* had brains averaging 1,200 ml or more, close to what humans possess today [1].

II. CURRENT UNDERSTANDING OF CRITICAL FACTORS

A. Size and Shape

Humans possess unusually large brains, even if we account for body sizes. However, studies have indicated that there is no strong relationship between brain size and intelligence in humans, as exhibited by the fact that the Neanderthal brain was just as big as ours, in fact probably bigger but not as capable. Our brains also have a different shape that indicates influence by genetic and environmental factors (plasticity). The shape of the human brain changes significantly during the first year of life. The developing brain picks up information from its environment providing an opportunity for the outside world to shape the growing neural circuits [1][2][3].

B. Language Comprehension

Language is probably the key characteristic that distinguishes us from other animals. Humans are compulsive communicators unlike other animals who can only understand some parts of our language and communicate for basic requirements through repetitive calls and symbolic gestures only. We can convey information rapidly and efficiently, coordinate and plan actions to other members of our species [2].

C. Environmental Impact

Human brain size evolved most rapidly during a time of dramatic climate change and larger and more complex brains enabled early humans to interact with each other and with their surroundings in new and different ways. As the environment became more unpredictable, bigger brains helped our ancestors survive [3].

D. Neocortical Wiring

The human brain contains about 10^{11} neurons and has an estimated storage capacity of 1.25×10^{12} bytes. Humans have far more white matter in the temporal cortex as compared to a chimp, reflecting more connections between nerve cells and a greater ability to process information. The ability to process information about the surroundings is a driving force behind evolution. The limit to any intelligent system therefore lies in its abilities to process and integrate large amounts of sensory information and to compare these signals with as many memory states as possible, and all that in a minimum of time implying heavy relevance on neural architecture and signal processing time. In mammals with convoluted brains, the cortical surface area, rather than being proportional to the $2/3^{rd}$ power of geometric similarity, is nearly a linear function of brain volume. The actual surface area of the human cortex is about 2000 cm^2, which is more than four times larger than would be predicted assuming geometric similarity, indicating that mammalian brains change their shape by becoming folded as they increase in size. Thus, the local wiring and cortical folding is a simple strategy that helps to fit the large sheetlike cortex into a compact space and keeps cortical connections short. An important evolutionary advantage of this design principle is that it enables brains to be more compact and faster with increasing size.[4]

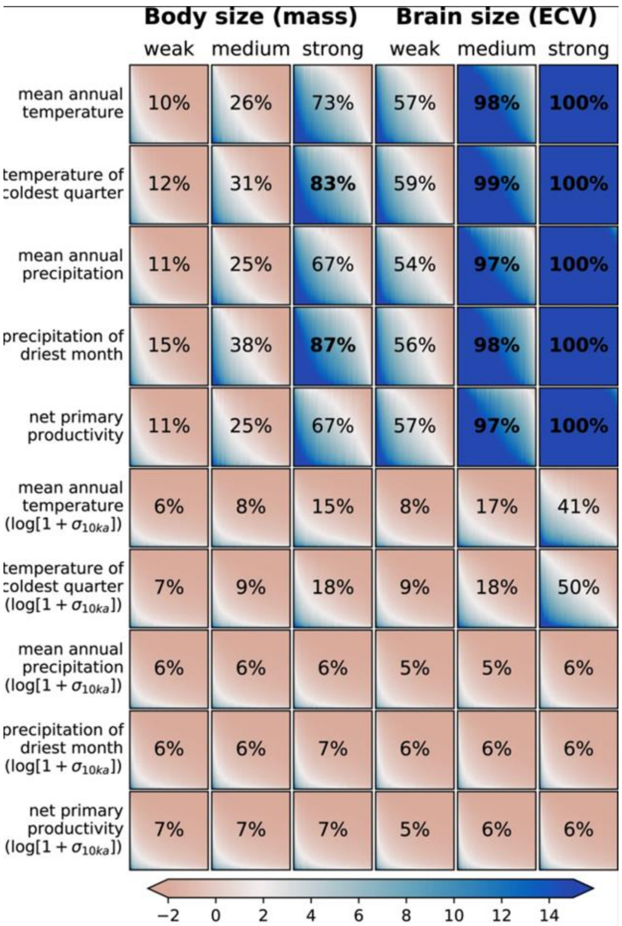

Figure 1. Power analysis for body and brain size data with environmental variables. [11]

E. Biological Limits

1. Energy limits

The human brain generates about 15 watts (W) in a well-insulated cavity of about 1500 cc. This creates a heating problem that needs to be taken care of lest it produce a thermal overload. Blood circulation through the brain acts as a heat drain. It provides cooling to delicate and metabolically expensive parts of the brain, such as the cerebral cortex. This vascular cooling mechanism would have served as a "prime releaser" that permitted brain size to increase dramatically during human evolution. So, a bigger brain would require cooler input blood or a faster pumping system. Thus, energetic considerations will dictate and restrict the size of any neuron-based system, but as theoretical analyses indicate, thermal and metabolic factors alone are unlikely to constrain the potential size of our brain until it has increased to at least ten times its present size.[4]

2. Neural Processing Limits

By modeling the information processing capability per unit time of a human-type brain they found that the human brain lies about 20–30% below the optimal, with the optimal processing ability corresponding to a brain about twice the current volume. Such a scenario is impractical due to the dynamic optimization trade-offs between neural organization, signal processing and thermodynamics. Consequently, primates with very large brains may have a declining capability for neuronal integration despite their larger number of cortical neurons.[4]

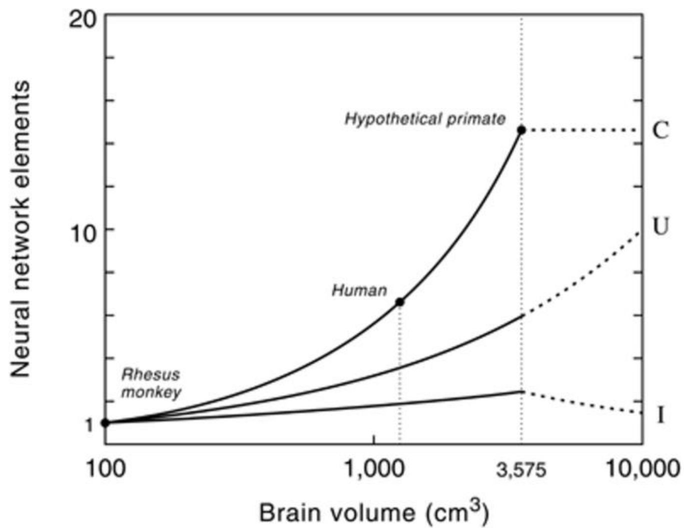

Figure 2. The number of connections (C), cortical processing units (U) and level of interconnectivity (I) in the primate neocortex as a function of brain size. Semi-logarithmic scale.[4]

3. Gestational limits

Bigger brain size would also mean changes in the female pelvic anatomy required for childbirth. It would cause higher maternal and fetal mortality, higher gestational period and postnatal development. [4]

III. RELATED PRIOR WORKS AND CONTRIBUTIONS

A. Dwindling Returns of Human Brain

For the fact, human brain size nearly quadrupled in the six million years since *Homo* last shared a common ancestor with chimpanzees, but human brains are thought to have decreased in volume since the end of the last Ice Age. Recent studies have also provided enough evidence for the same and reported that human brain size reduction, which has been a rather recent phenomenon since around 3000 years, has not been only due to decrease in body size due to agricultural diet but rather associated to the need for enhanced social intelligence (Dunbar, 1998; Dunbar and Shultz, 2017) and increase in complexity of social life. Hawks (2011) emphasized that given the correlation between human brain and body size (Holloway, 1980), the observed 5 kg decrease in body size in the Holocene would account for only a 22 mL decrease in brain volume (Hawks, 2011). However, the actual reduction is more than 5x greater, indicating the fact that body size alone cannot entirely explain the decrease in brain volume [9].

Industrial societies in the past 100 years, however, have seen brain size rebound, as childhood nutrition increased, and

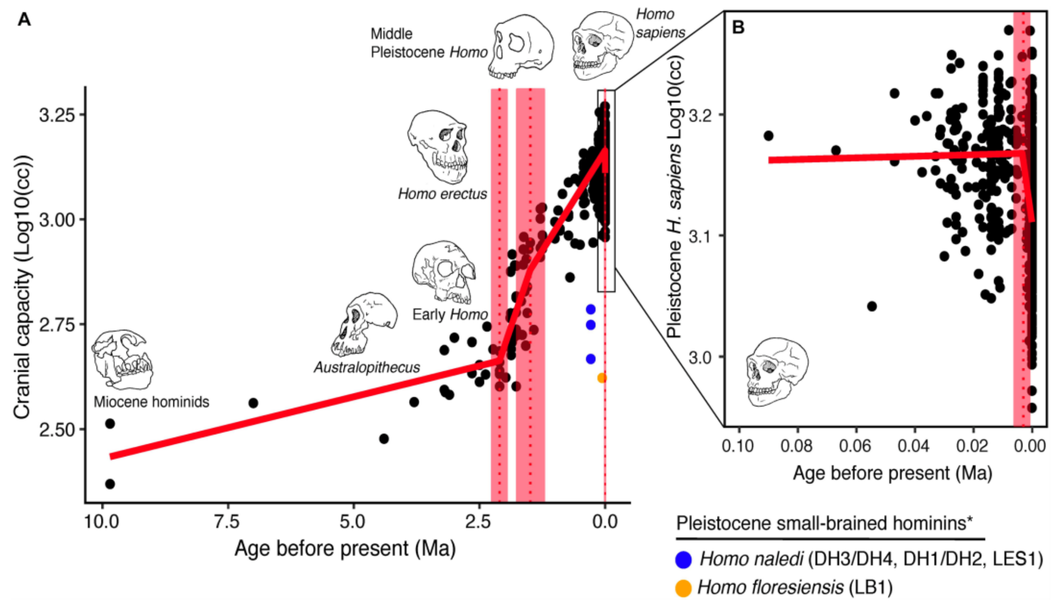

Figure 2. Trends in Hominin Brain evolution
(A) Cranial capacity in fossil apes and hominids over the last 10 million years.
(B) Changes in brain size in last 100,000 years in Homo Sapiens

disease declined. However, size often doesn't reveal the complete story and it is possible that the brain has simply evolved to make better use of less gray and white matter. Some genetic studies suggest that our brain's wiring is more efficient now than it was in the past, however others believe that the shrinkage is a sign of a slight decline in our general mental abilities. David Geary at the University of Missouri-Columbia, for one, believes that once complex societies developed, the less intelligent could survive on the backs of their smarter peers, whereas in the past, they would have died – or at least failed to find a mate. Multiple studies have indicated that the more intelligent people tend to have fewer children. Resource sharing within groups may have provided the energy surplus needed to support the increased energetic cost of a larger brain (Isler and van Schaik, 2012).

B. Ants and Humans: A Comparative Study

Ants have nevertheless emerged as important models for understanding the role of sociality (Ilies et al., 2015; Kamhi et al., 2016, 2019; Godfrey and Gronenberg, 2019) and behavioral performance and cognition (Muratore and Traniello, 2020; Muratore et al., 2021) in brain evolution. The vast ecological diversity of ants encompasses forms convergent in aspects of human sociality, including large group size, agrarian life histories, division of labor, and collective cognition. Despite possessing brains of vastly different structures with size, neuron number, and synaptic connectivity of an ant brain being a diminutive fraction of a human brain, the two possess similarities including remarkable computational power for its size and miniaturization does not appear to constrain behavioral performance and/or higher-order processing, social learning, or consciousness (Avarguès-Weber and Giurfa, 2013; Barron and Klein, 2016; Perry et al., 2017; Lihoreau et al., 2019; Perry and Chittka, 2019; Elek et al., 2020; D'Ettorre et al., 2021).This latter comparison among agricultural ant species provides insight into how increased group size and sociality in human populations may have reduced brain size (Bailey and Geary, 2009) due to a high level of emergent complexity [9].

C. Natural Limits to the Brain Development

Some argue that the human brain has almost reached the limits of information processing that a neuron-based system allows and that our evolutionary potential is constrained by the delicate balance maintained between conduction speed, duration of the electrical pulse, synaptic processing time, and neuron density. Any further enhancement of human brain power would require a simultaneous biological improvement. One would also need to account for the increase in size of heart, to power the brain effectively. At a brain size of about 3500 cc, the brain seems to reach its maximum processing capacity. The larger the brain grows beyond this critical size, the less efficient it will become, thus limiting any improvement in cognitive power. Therefore, to keep up with the current levels of intelligence, genetic engineering might prove to be an effective way forward.

D. Technological Assistance: The Way Forward

Researchers are already working on projects to integrate technology with human bodies and enhance our capabilities: developing cochlear implants and digital retinas to help the deaf hear and the blind see [7]. Another way to do so is by replacing the traditional interface of the brain from visual and auditory to tactile and such advancements have already been taken up for sensory inputs on tongue and forehead. [6]. Cybernetic arms have also come to the aid for people with injuries or impairments by acting as an interface with the human brain [7]. Recent advancements in areas of nanotechnology, information technology, neuroscience and biotechnology are leading towards the development of Brain Machine Interfaces (BMIs). BMIs function by interpreting and translating neural activity into computers and prosthetic devices and the primary reason for their success is their ability to extract information of neural activity in a chronological order (Sanchez et al., 2004, p.943) [10].

IV. DIRECTIONS FOR FUTURE WORK

Roboticists at Carnegie Mellon University estimated that computers will surpass our processing capacity by 2030 [source: Lavelle]. So, as futurist Ian Pearson suggests, we might need to consider supplementing the human brain with a computer interface. This would suggest evolution to a species *Homo cyberneticus*, which is slightly assisted by silicon enhancements & with positive outcomes, this could pave the path for computer-based *Homo hybridus*. One of the major flaws he considers is that the organic part of the body would eventually wear out and die, itself leading to *Homo machinus* which could possibly suggest chances for self-impairment and thereby, immortality. Systematic, controlled and ethically acceptable pharmacological intervention in human brain functions can provide an alternative, or a complement to information technology intervention into the operation of human minds. A promising application of BMI research in future is in restoration of movement to brain stem stroke paralyzed people [10]. With time, the human nervous system could be replaced with 'plug-and-play' devices with immaculate control and limitless processing of data [7].

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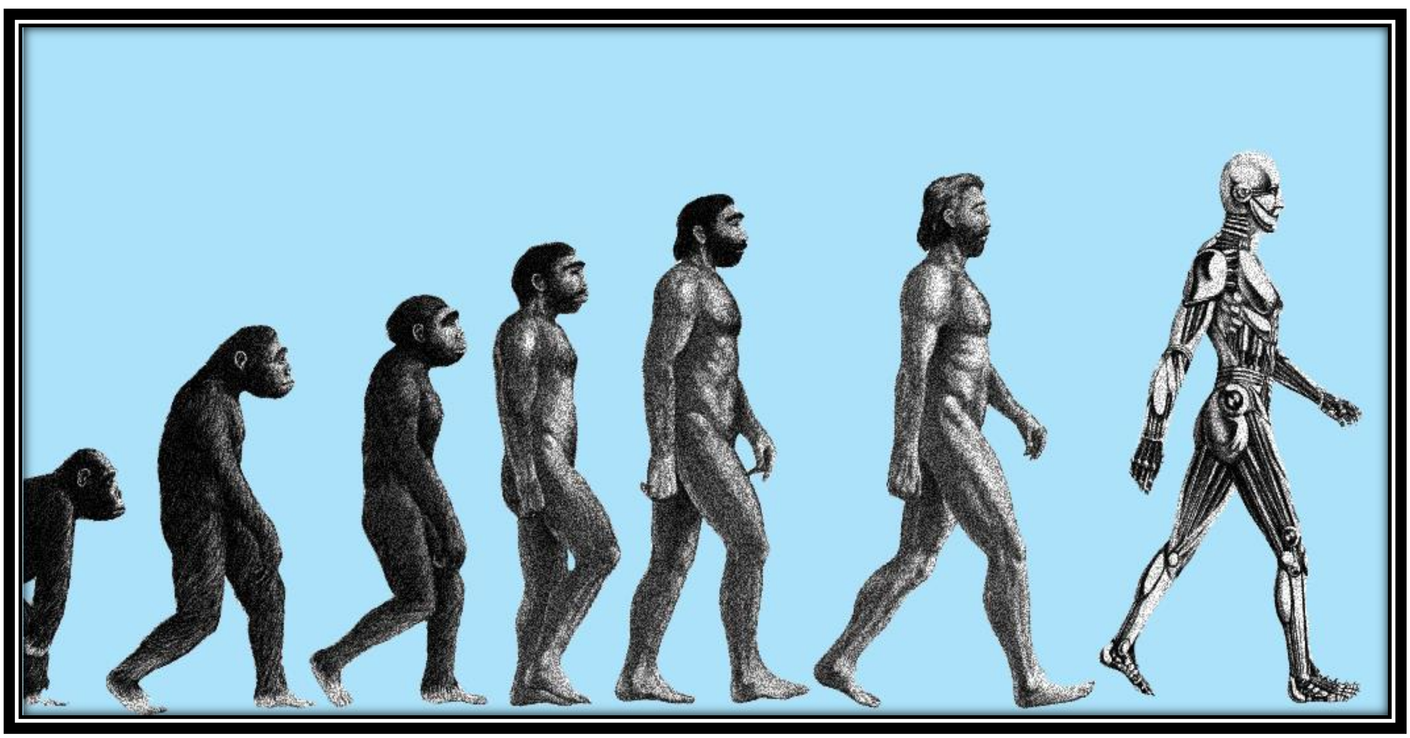

"In creating the human brain, evolution has wildly overshot the mark."
- Arthur Koestler, author