Adapting to Thrive: How the Evolution of Brain Physiology Shapes Human Behavior

Montserrat Sahagún[1] and Sergio Samuel Montañez[2#]

[1]Instituto Educativo Olinca, Mexico
[2]Universidad Panamericana Ciudad de Mexico, Mexico
[#]Advisor

ABSTRACT

In this paper we analyze diverse theories about the workings of the mind and the evolutionary trajectory of brain physiology, giving rise to species-typical mechanisms in human cognition. Evolutionary psychology has shed light on how a computational theory of the mind elucidates the development of specialized psychological programs, enhancing our fitness based on ancestral conditions. An example of such adaptation is the expansion of the prefrontal cortex relative to body size, particularly among primates. This enlargement fosters the formation of intricate social structures, leading to more extensive groups and refined social dynamics. Interestingly, this positive link between brain size and social structure holds true for both humans and non-human primates. Recent strides in neuroscience and brain technology have enabled us to uncover the primary brain regions influencing social cognition, executive function, and emotional processing. Brain areas including the frontal lobe, prefrontal cortex, insular cortex, cingulate cortex, hypothalamus, and others intricately shape learning, emotion regulation, and decision-making processes. Therefore, the evidence for the evolutionary theory of the mind and its implications for behavioral neuroscience are undeniable.

Introduction

From an evolutionary perspective, the criteria for assessing whether a specific human trait qualifies as an adaptation, encompassing common psychological traits and behaviors, entail that the trait represents a complex design tailored for a domain-specific function and lacks alternative processes that can account for such complexity. According to Williams (2018) definition, an adaptation is a biological mechanism shaped by natural selection for a particular purpose, which can be evaluated in terms of engineering economy and efficiency. This dual complexity and efficiency verify its status as an adaptation. Tooby and Cosmides (1989) argue that adaptations inherently exhibit relatively low variation to manifest as species-typical designs. They further underscore that for a mechanism to be considered an adaptation in the context of humans, it must have been suitable for the Pleistocene-era African savannah ecology where our ancestors evolved. Moreover, the intensity of selection pressure corresponds to a higher degree of specialization to address the given adaptive challenge within the ancestral milieu. An instance proposed by Pinker and Bloom (1990) pertains to language acquisition and development. Their argument posits that language is an adaptation in humans, substantiated by the fact that all human societies, regardless of age or origin, exhibit the ability to acquire language without formal instruction. The shared structural elements across diverse languages and the capacity of infants to learn virtually any language underscore the existence of a species-typical design.

Over the course of decades, most social sciences—such as psychology, anthropology, sociology, economics, and history—have exhibited reluctance to integrate biological and evolutionary theories into their methodologies. This hesitance stems from factors like limited knowledge of biology and concerns arising from historical events where biological concepts were misused against marginalized groups, such as during Nazi Germany. However, modern advancements in neuroscience and evolutionary psychology have demonstrated that the brain's physiology evolved to possess a universally functional organization based on its species-typical design. As noted by Tooby et al. (2003), "The second law of thermodynamics is the first law of psychology," reflecting how Darwinian natural selection enabled organisms like humans to thrive amidst entropy, manage their environment, and ensure survival and reproduction.

Many learning theorists in fields such as psychology, education, and neuroscience uphold the notion that neurocomputational mechanisms and developmental processes are domain-general and not tied to specific content. This viewpoint prevails in the social sciences, where the social constructionist perspective often informs learning inquiries. However, substantial evidence indicates that evolutionary pressures have shaped the brain's physiology and neural architecture, enabling it to create content-specific computational programs akin to Kantian categories. Consider, for instance, the widespread fear of spiders, snakes, and dark-dwelling monsters among most individuals, including non-human primates like chimpanzees. Conversely, people, especially those residing in urban areas—where the majority of the population resides—are generally not afraid of cars despite having either experienced car accidents themselves or witnessing them as they mature. This prompts the question: If fear were largely learned and the brain operated under a general domain learning mechanism, people would presumably exhibit a greater average fear of cars than of spiders, snakes, or monsters. However, this is not the case.

Michael Gazzaniga, a prominent figure in cognitive neuroscience, gained renown for his role in popularizing and pioneering split-brain studies among human patients during the 1970s. These studies facilitated an understanding of brain function and specialization. Split-brain research involves investigating the cognitive consequences of severing the corpus callosum through a procedure known as complete callosotomy. Collaborating with notable biologist Roger Perry, Gazzaniga's work laid the foundation for exploring cerebral hemisphere functions. In subsequent years, Perry earned the Nobel Prize in Medicine for his research into the functional specialization of cerebral hemispheres. Later on, Corballis and his peers contributed to this field by demonstrating that the left hemisphere primarily governed language dominance, whereas the right hemisphere specialized in visuospatial processing. Furthermore, evidence has shown that damage to the right hemisphere can impact the ability to recognize familiar faces (Gazzaniga, 2005). Therefore, the physiological evidence of brain specialization underpins the intrinsic psychological mechanisms that shape our subjective experiences.

The Brain in Human and Non-human Primates

In 1973 Jerison pointed out that primates have unusually large brains compared to all vertebrates (Dunbar, 2009). Shultz and Dunbar (2012) proposed the social brain hypothesis where they argued that the complex social interactions between primates drove evolutionary pressures to develop higher cognitive capacities, and thus, larger brain size. The authors classify humans as anthropoid primates, which include primates and apes, given the proportion of brain size to their bodies. Dunbar (1992) hypothesized that primate cognition evolved to solve the problem of social bonding and integration with evidence supporting that brain size correlates positively with group size among primates. Deception rates, mating strategies, grooming clique size, and coalition rates, are among the factors that demonstrate the correlation between neocortex size and group size in primates. Bshary *et. al.* (2007) showed evidence that supported that commonly thought as only-human phenomena like culture, teaching and reciprocity can also be found among non-primates species which presumes that these activities are not as socially demanding as once thought. Researchers have identified theory of mind (ToM) intentionality levels as a distinguishing feature in higher-level cognitive abilities with great primates. Human-level intentionality is usually found between third and seventh-order intentionality. Neuroimaging studies have provided evidence of the specific brain regions responsible for the executive control and emotional salience of ToM capabilities, finding that the most relevant regions are the medial prefrontal and orbitofrontal cortex in 93% of studies, temporoparietal junction in 58% of studies, and the anterior cingulate cortex in 55% of studies. Dunbar (1998) found a significant correlation between the neocortex size between different primates and their average group size.

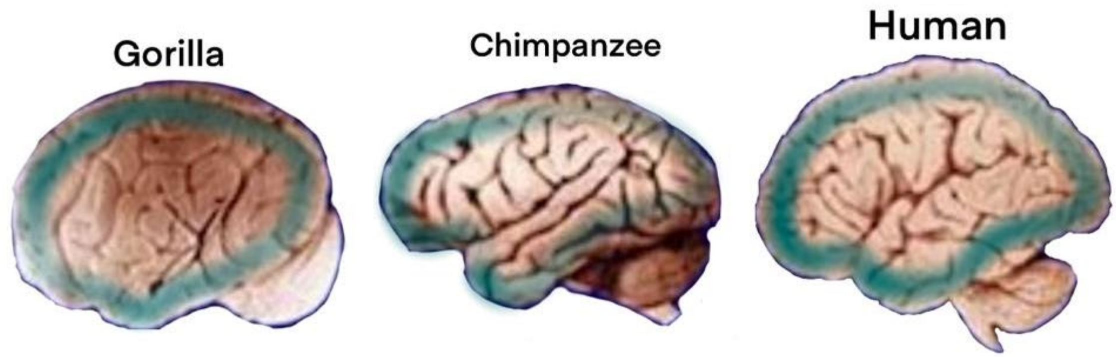

Figure 1. Shows the comparison between the size of the neocortex in gorillas, chimpanzees and humans. As discovered by Dunbar (1998), the size of the neocortex has a positive relationship with the species group size which suggests a physiological link to the theory of mind (ToM) hypothesis.

Dunbar (2009) asserts that brain size in anthropoid primates is a monotonic function of brain size. However, this tendency has not been found in all species, for example birds, where social group size does not correlate with brain size. Finally, there is also evidence that species with lifelong pair bonds as some primates and humans have larger brains compared to species that mate polygamously. Dunbar (2009) argues that selection pressure for larger brain sizes was largely driven by the cognitive demands of having a lasting pair bonding mate system.

Brain Physiology Shapes Human Behavior

Damasio *et. al.* (1994) showed that emotional and social significance, which regulate personality, empathy and social behavior, are mainly regulated by the ventromedial PFC links. Shultz and Dubar (2011) identified the insula, frontal lobe and prefrontal cortex as those brain areas that have expanded the most in humans versus other brain areas and are the distinguishing features compared to non-human primates. This led them to conclude that these areas are mainly responsible for executive function and social cognition. Furthermore, Damasio (2000) showed that brain structures like the insular cortex, secondary somatosensory cortex, cingulate cortex, and nuclei in brainstem tegmentum and hypothalamus are directly related to the representation and regulation of feelings and emotions.

Sanfey *et. al.* (2003) analyzed participants and scanned their brains through functional magnetic resonance imaging (fMRI) while playing a splitting money game (so-called "ultimate game" in economics) and found significant activity in the anterior insula, dorsolateral prefrontal cortex (DLPFC), and anterior cingulate cortex when participants got an unfair offer. The authors argue that anterior insula activation is consistently seen in neuroimaging studies of pain and stress, (DLPFC) is found in tasks requiring goal maintenance (accumulating money), and the anterior cingulate cortex is found in situations in conflict with cognitive and emotional motivations. The DLPFC dictates according to "rational expectations" that individuals accept any amount of money higher than 0, while the anterior insula increases its emotional effect as the unfairness level increases, creating a conflict between the two. This demonstrates empirically that utility theory in economics is in many cases wrong and not universal.

In a study performed about the adaptive mechanism of decision-making in humans when choosing an option that involves short-term costs and long-term benefits, Frank and Claus (2006) found that the brain systems involved in such behavior were the basal ganglia (BG), the neuromodulator dopamine (DA) and the orbitofrontal cortex (OFC). These systems are associated with reinforcement learning, reward associations, and working memory. The key insight is that the basal ganglia and dopamine systems provide the learning mechanism to make decisions based on the probability of positive outcomes, while the orbitofrontal cortex is needed to keep active working memory of the gain-loss information's relative magnitudes. The two systems working together results in a better understanding of the expected value.

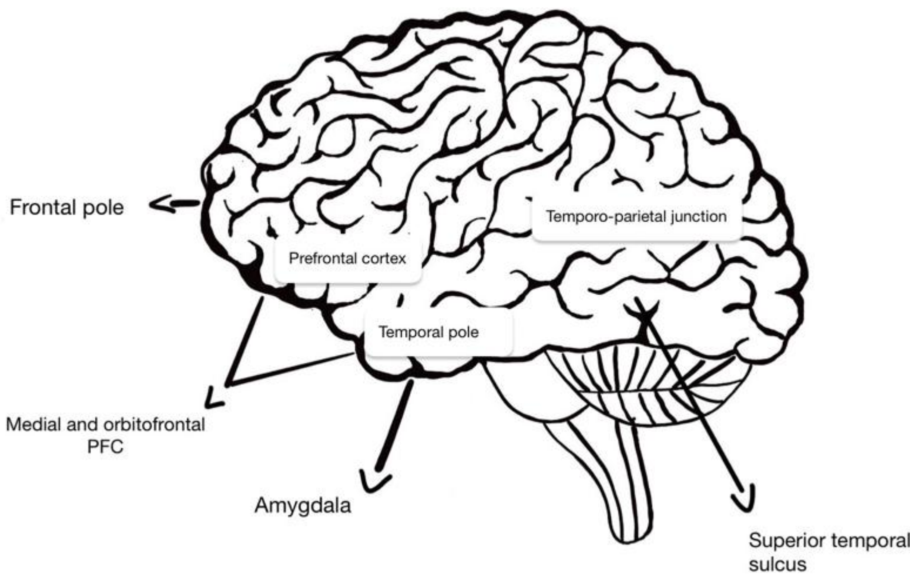

Figure 2. Major regions of the human brain relating to social and cognitive skills. The anterior cingulate cortex is found in the back of the prefrontal cortex as well as the insular cortex and the basal ganglia is at the center above the amygdala.

Sexual Differences in Psychological Adaptations

Regarding individual differences in personality and behavior, Buss (1999) argues that personality differences show moderate heritability in a range of 30% to 50%. Then personality is partly a species-typical evolved psychological mechanism. In terms of sexual differences among the human species there is evidence of sexual dimorphic adaptations that evolved due to different challenges that males and females had in ancestral times (Krasnow *et. al.*, 2011).

New *et. al.* (2007) found that among hunter gatherers, males focused mainly on hunting and were opportunistic gatherers while females were mainly gatherers in human tribes which should cause that cognitive mechanisms that evolved were sexually dimorphic. The authors find evidence that women outperform or have a higher preference than men in spatial memory in a specific type of navigation involving gathering, taste preference for fruits versus meat, color sensitivity towards fruit-like colors, and scent sensitivity towards fruits versus other common types of smell. Following the work of Silverman and Eals (1992), the authors argue that women should excel in navigation tasks involving stationary content-specific navigation, in this case remembering and locating high nutritional resources (e.g. fruits and vegetables). These activities differ from the type of navigation that ancestral men constantly faced while hunting where they followed a moving target. Indeed, New and coauthors found compelling evidence that women are better than men at remembering spatial locations that contain high nutritional resources. In addition, Jameson *et. al.* (2001) found evidence supporting the previous hypothesis, if women are better at detecting gatherables like fruits in stationary locations their visual system should have evolved an adaptation to outperform men. The authors show that women with four-photopigment genotypes perceive much more chromatic appearances than women or men with three classes of retinal photopigments; color vision is a sex-linked trait. Their models explain why women's skill to identify primary colors is greater than men's by age 5-6 and why women with four four-photopigments show a finer color discrimination ability than both men and women with three retinal photopigments. Finally, the olfactory lobe directly connects with the limbic system which enables it to influence behavior. Hirsch *et. al.* (1998) found that common neurotransmitters facilitate both sexual and olfactory functioning.

A Neurocomputational Perspective of the Brain

Friston *et al*. (2017a) introduced the Bayesian brain model, presenting neuronal dynamics as a generative model. They propose that "action fulfills predictions based on inferred states about the world." Humans employ active Bayesian inference, predicting outcomes from sensory data and constructing reality through a generative model grounded in observed outcomes and goals. The Bayesian algorithm encompasses both an exploratory epistemic aspect and a functional pragmatic facet. In a Markovian decision model, state transitions hinge on actions influenced by future beliefs formed through the generative model, drawing from past experiences and goal optimization.

According to Jefferys and Berger (1992), the Bayesian statistics perspective suggests that the brain must update prior beliefs to account for sensory data and address the intricacies of the world. Parr *et al.* (2023) adopt the Bayesian inference approach to elucidate how demanding cognitive processes necessitate probabilistic belief updating or prior beliefs in mathematical terms. New actions allow individuals to gather fresh information for future use. Building on Parr and Friston's work (2018), the authors posit that the neuronal architecture for belief updating aligns with the brain's generative model. In their study, Parr and colleagues (2023) employ the renowned color-text Stroop Task to outline a temporal generative model of information processing in the brain and delineate the brain's functional anatomy from a computational viewpoint. Figure 3 illustrates a graphical depiction of the brain's computational anatomy based on their research, elucidating key brain regions involved in processing sensory information.

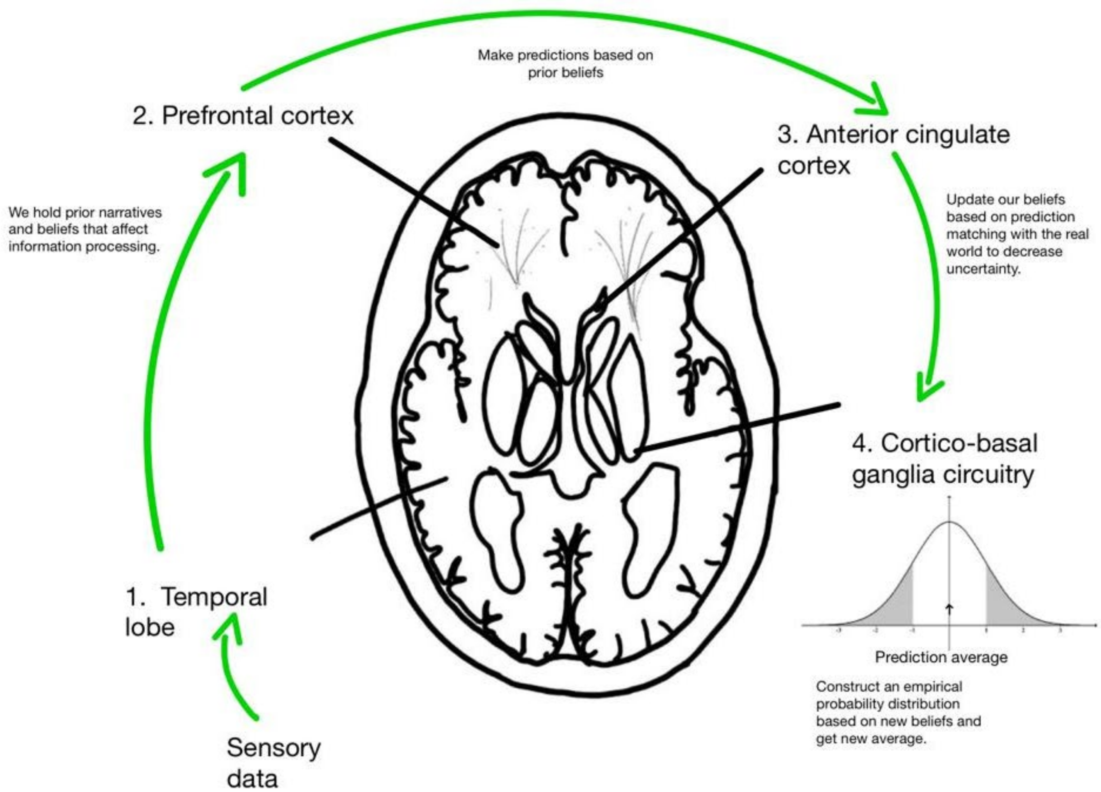

Figure 3. Neurocomputational generative model of the brain based on Bayesian active inference. The mind computes the posterior probability of unknown events based on prior beliefs, outcomes and goals. Our goals affect our predictions since we seek to decrease uncertainty.

Computational Anatomy of the Brain Information Processing

1. First interaction between the senses and the world, the brain receives sensory data which may come through the visual system, auditory and/or tactile. Information is processed at the **temporal lobes.**

2. Afterwards beliefs about narratives are associated with the hippocampi according to several authors (Foster and Wilson, 2007; Frolich ̈ *et al.*, 2021; Huerta and Rabinovich, 2004; Pezzulo, Kemere and van der Meer, 2017) and share connections with the **prefrontal cortices** (Fuster, 1973).

3. Prior beliefs are used to probabilistically update our beliefs about our prediction and match this prediction with the real world, thus generating tangible consequences that allow us to optimize our beliefs to reduce uncertainty and increase accuracy. Some authors state that this updating process involves the **anterior cingulate cortex** (Scherbaum et al., 2012; Shenhav *et al.*, 2013, 2017).

4. Based on previous actions and their positive or negative consequences, humans gather new information and the brain constructs an empirical probability distribution based on conditional beliefs, resulting in a Bayesian model average. According to Friston *et al.*, (2017) this Bayesian process has a similar architecture to the **cortico-basal ganglia circuitry.**

Discussion

We have refined various theories about the mind and how brain physiology evolved to give rise to species-typical mechanisms of human cognition. Evolutionary psychology has illuminated how a computational theory of the mind enables us to understand the development of specific psychological programs that enhance our fitness based on ancestral conditions and environments. An illustrative adaptation is the expansion of the prefrontal cortex in comparison to other animals, particularly primates, relative to body size. This expansion facilitates the creation of more intricate social structures, leading to larger groups and more sophisticated social dynamics. Notably, this positive correlation between brain size and social structure is observed in both humans and non-human primates. Furthermore, advancements in modern neuroscience and brain technologies have allowed us to begin uncovering the brain regions that predominantly influence social cognition, executive function, and emotional significance. Brain areas such as the frontal lobe, prefrontal cortex, insular cortex, cingulate cortex, hypothalamus, and others contribute to shaping processes like learning, emotion regulation, and decision-making.

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