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Brain Reorganization Allowed for the Development of Human Language: Lunate Sulcus

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Abstract

This article presents the hypothesis of a connection between eidetic memory and the lunate sulcus, a feature that was repositioned during evolution. Humans have evolved from ape-like ancestors for 7 million years. Along with a prominent increase in brain size, the reorganization of the brain marked by the sulcus generated the evolutionary momentum toward the development of human language. This article reviews the reorganization of the human brain using an interdisciplinary approach of examining animal behavior and anthropological and biological studies. This brain reorganization must have occurred during early maturity and is thought to be responsible for eidetic imagery in some adolescents and superior short-term memory in chimpanzees. During early development, the neural connections in prefrontal cortex and posterior parietal lobe rapidly expand, while visual memory capacity of human brain would become limited. Biological studies have demonstrated that the lunate sulcus is subject to white matter growth, and dental fossil and tomography studies have shown that the brain organization of Africanus is pongid-like.

Keywords: eidetic memory, lunate sulcus, Einstein, chimps, gray matter

1. Introduction

The principles that govern the evolution of brain structure are controversial. The timeline of hominin evolution spans approximately 7 million years, and the re-arrangement of the brain during human evolution is thought to have been more organizational than volumetric (Balter, 2007). Particular milestone changes in the position of surface anatomical features, such as the simian sulcus, suggest that the brain underwent internal reorganization (Bruner, 2014). It is argued that the evolutionary expansion of the frontal areas of the lunate sulcus would have caused a shift in the location of the fissure (Rincon, 2004).

2. Animal Behavior Studies

In set of short-term memory tasks, such as memorizing the sequential order of numerals and recalling them, the performance of young chimps was shown to exceed that of human adults (Matsuzawa et al., 2007). Chimpanzees are apparently superior to humans at achieving instantaneous memorization. Matsuzawa indicates an evolutionary tradeoff between the eidetic/photographic memory of these chimps and the higher cognitive abilities of humans, such as the advanced capability for complex language (Choi, 2007). In this regard, the simian sulcus, also known as the lunate sulcus, is an anatomical fissure between the temporal and occipital lobes that is found in primates (Allen et al., 2006). Intriguingly, the sulcus lunatus lies in the back of human brains and has a more frontal location in chimpanzees (Holloway, 1974).

Moreover, chimpanzees at the California Institute of Technology played a hide-and-seek computer game and bested African villagers and Japanese undergraduate students. The computer program was based on game theory and examined the abilities of individuals to predict their opponent's move (Martin et al., 2014). The chimps were more successful than humans at this game because they have strong short-term memory and talents for pattern analysis.

The human brain has greater capacity than the chimp brain. Humans have the largest and most complex brains of any living primate. The brain capacity of the modern human is three times that of apes, with the human brain having a larger structure and more neurons (Lieberman, 2011); however, increased brain size in humans cannot solely explain the superior cognitive ability of chimpanzees described above. The stronger short-term memory demonstrated in chimps compared to humans must be due to structural differences in the brains of these two species. Holloway stated the importance of the reorganization of the human brain during evolution, referring to the posterior location of the lunate sulcus (Balter, 2007).

3. Child Behavior Studies

It has been long been thought that adults surpass their younger childhood selves in every intellectual, neurological, and biological measure. Surprisingly, researchers have observed eidetic imagery in children 6 to 12 years old, while photographic memory abilities have generally not been documented in adults (Searleman, 2007). This particular skill fades as children mature. Interestingly, no associations were found between the ability to generate photographic memories and any cognitive or emotional level.

In a similar context, several studies revealed that six-year-olds were better than adults at distinguishing discrete information (Nardini et al., 2010). In fact, adults performed worse at answering whether the angle of a particular disc was the same as that of other discs. That study demonstrated that adults combine multiple pieces of visual data into single pieces of data, while kids perceive visual data separately. This integrative capability obtained in adulthood has a cost. Vladimir Sloutsky of Ohio State University states that people categorize information as they become mature and intelligent, resulting in lower accuracy of memories of individual characteristics (Wahl, 2013).

In another psychology experiment, test groups consisting of adults and children as young as 5 years old were shown pictures of animals. After scientists provided a dummy task of looking for "beta cells" in the animal pictures, the subjects were again shown 28 more images and were asked if they had seen the image before. To the researcher's surprise, the young participants performed better than the adults. These results were attributed to visual confusion caused by integrative processing in adults and also provide and explanation for the remarkable eidetic memories of some children (Sloutsky & Fisher, 2004).

The size of the brain size and the number of neurons it contains increase as children enter adulthood (Blakemore, 2012). Nevertheless, the ability to identify separate information and eidetic memory are more prominent in children than adults. As previously mentioned, chimps have also been shown to have superior performance over adult humans in short-term memory tests. Eidetic memory and individual identification abilities are lost as children enter adulthood and the brain grows.

I hypothesize that evolutionary pressures resulted in the human brain undergoing internal reorganization to develop the capability of human language. Furthermore, this reorganization must have been implemented during early maturity and is likely responsible for eidetic imagery in some adolescents. Specific details of rearrangement of different brain structures, such as white matter, the lunate sulcus, and the prefrontal cortex, will be mentioned in the following descriptions of biological studies.

4. Biological Studies

Einstein died on 17 April 1955 and made an elegantly famous statement at the time of his death, "I have done my share; it is time to go" (Cohen & Graver, 1990). This great 20th century physicist donated his brain for medical use. For decades, the brain of this distinguished scientist has attracted avid researchers and curious audiences, as it was the first historical brain to be dissected, and its dissection generated an astounding result. The brain autopsy suggested that regions involving speech and language are small compared to areas involved in numerical and spatial processing. Other studies have supported Einstein's claim that he thought visually rather than verbally. The lateral sulcus (Sylvian fissure) was absent in Einstein's brain, and importantly, the lunate sulcus was not prominent in Einstein's brain (Falk et al., 2013).

4.1 Explaining the Sulcus

Sulci are depressions or grooves in the cerebral cortex; they surround a gyrus and create the characteristic wrinkled appearance of the brain in humans and other mammals (Carlson, 2009). They are relatively shallow grooves that surround a gyrus compared to bigger grooves called fissures that divide the brain into lobes. The gyri, fissures, and sulci generate a larger surface area of the human brain and other mammalian brains. Furthermore, the folded structure of the brains of humans and some intelligent mammals generates a larger surface area, which allows for greater cognitive power.

It has been stated that the development of the sulcus varies greatly between individuals; furthermore, the structure of the sulcus varies greatly with age. However, the factors that determine the iconic shape of the gyri and sulci in the human brain are not entirely clear.

4.2 What may be the Reason

Researchers that refuted traditional models of sulci development in the human brain, described different growth rates of gray and white matter as key to understanding the development of sulci. Comparatively faster growth of gray matter (top layer) would pin down the white matter to mold the shape of the cortex (Tallinen et al., 2014). Surprisingly, human infants, unlike baby chimps, experience a developmental stage during which white matter that establishes neural connections in the brain shows dramatic expansion, and this causes reorganization of sulci, in this case, the lunate sulcus.

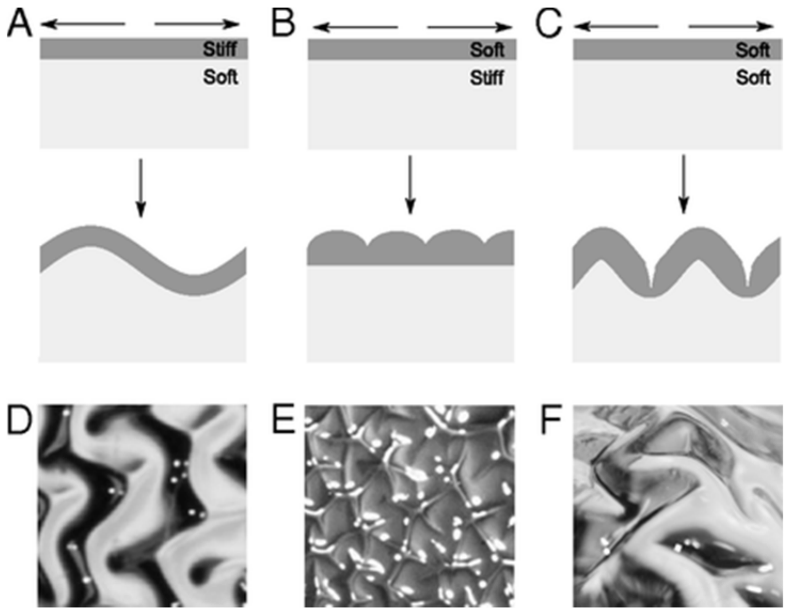

Figure 1. Sulcification in a layered material based on differential growth of white matter and gray matter. The top layer stands for gray matter, and the bottom represents white matter.

Source: Tallinen, Chung, Biggins, and Mahadevan (2014).

4.3 Gray/White Matter

The gray and white matters of the brain have important functions. The gray matter is in charge of cognition and transports nutrients and energy to the brain. Conversely, the white matter orchestrates action potentials and coordinates, or communicates, between brain regions (Fields, 2008). The sulcus lunatus is an anatomical fissure between the temporal and occipital lobes that is also observed in chimpanzee brains, but in a more anterior location (Falk, 1983). In chimps, the fissure is marked by a smaller amount of white matter growth, allowing for freer connections between the two lobes and allowing for the storage of visual memories. The dramatic expansion of the prefrontal lobe and posterior lobe that developed during the evolution of humans and occurs during a child's growth, resulted in a more posterior location of the sulcus.

Although brain volume increases during child growth, gray matter wanes through a pruning process. Fast growing white matter replaces the waning total volume of gray matter, allowing interactions between different parts of the brain. MRI comparison studies have shown that brain regions in children have short, localized connections that become longer in adults (Petersen et al., 2009). The process of replacement of gray matter in adolescence is called synapse-pruning and is described in the vernacular simply as, 'use it or lose it.' In humans, the temporal lobe forms longer connections to the posterior parietal lobe (Wernicke's area) and prefrontal cortex (Broca's area), areas essential to language-learning and overall cognition, rather than to the occipital lobe, which lies adjacent to the temporal lobe. More surprisingly, memory studies in hunter-gatherer societies indicated that pre-literate tribal groups excel in visual memory (Madden et al., 2006). An aboriginal forage society without a writing system would rely more on eidetic memories for information processing and, thus, survival (Kearins, 1981). In contrast, in contemporary societies, eidetic memory becomes obsolete and children's brains are devoted the learning of language, numbers, and social cognition. As a direct result of synapse-pruning in humans living in modern societies, the specific location of the sulcus in humans, which is set by explosive growth of white matter, results in limited connections between the temporal and occipital lobes.

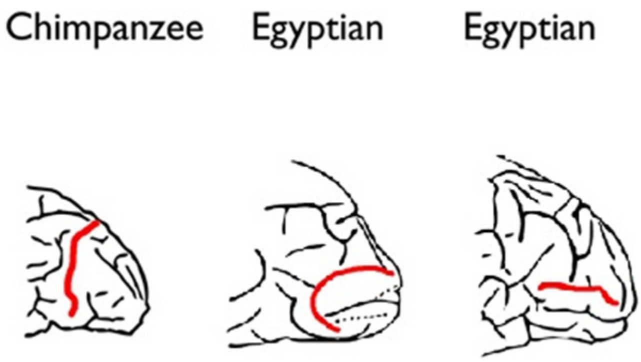

Figure 2. Specifically, fast growing white matter in adolescence was the key change in the evolution of intelligence. This molds the brain making it capable of language while comparatively allowing for fewer connections between the prefrontal cortex and occipital lobe and, thus, resulting in a less active occipital lobe. The growth of white matter also accounts for sulcus variation with age

Source: Falk (2014).

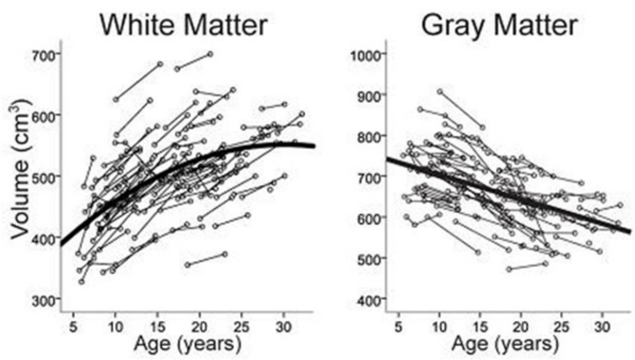

Figure 3. Gray matter decrease offsets white matter increase in brain

Source: Lebel and Beaulieu (2011)

5. Conclusion

Superior memory abilities have been demonstrated in children and chimps whose brain capacities and number of neurons are far less than those of the adult human brain. Hominin brain size has dramatically increased over millions of years, and studies have confirmed that evolutionary changes in the brain occur during child development. Active development of particular brain regions in the posterior parietal cortex (sense of self), prefrontal cortex (social cognition), and temporal lobe (language interpretation) occur in the early years of life (Gogtay, 2004). Fast growth of white matter in specific areas replaces localized regional linkages of brain sections and is accompanied by a shift of the sulcus and the loss of the superb short-term memory observed in chimps and human children.

Many animals besides chimps depend on eidetic memories for survival. For example, eastern gray squirrels excel at remembering landmarks and retrieving food from caches. However, our ancestors eventually did not require photographic memories. Evolutionary changes, intricate hunting tools, and the use of fire, shelter and recordkeeping gradually enabled satisfactory survival independent of short-term visual memories. Humans have built rich, protected shelters and do not need to pinpoint the exact location of predators or food.

5.1 Answering the Lunate Sulcus

The debate about the interpretation of a depression in australopithecine between physical anthropologists Holloway and Falk is ongoing (Holloway, 1984). Holloway argues that sulcal patterns in australopithecine indicate cerebral organization more like that in modern hominins, while Falk insists that the lunate sulcus is in a position that indicates an ape-like pattern (Falk, 1987). The argument extends from the AL 162-28 endocast to all australopithecine fossils (Holloway, 2004). Holloway states the presence of present-day hominid sulcal features, while Falk maintains that the features are pongid in nature.

In a recent tomography study of the Taung Australopithecus africanus fossil, Carlson and colleagues failed to find any signs of human-infant skull features (Holloway et al., 2014). Previous studies suggested that features of the Taung specimen would allow the child's brain to grow rapidly, similar to brain growth in modern home sapiens. Nonetheless, new brain CT scans of the Taung Australopithecus africanus fossil have shown that it lacks these features.

The timing of the evolution of dramatic changes in the hominin brain has been indicated by dental fossil studies. Researchers, including Christopher Dean, analyzed growth patterns in the enamel of fossil teeth recovered from a wide array of early human ancestors (Dean et al., 2001).

The scientists did expect that Homo erectus— indicative by its name "upright man," the first human ancestor to show modern human-like characteristics in terms of body proportions, weight and jaws --would show evidence of a modern human-like postnatal growth period.

However, the results proved otherwise and suggest that the prolonged interval of childhood may have occurred in the recent development of the large human brain—a period of growth that is considered a key event in human evolution by increasing the time available for learning.

Overall, studies have indicated that the hominin brain growth observed in modern humans may not have evolved until recently in the course of evolution, and this confirms Falk's hypothesis that australopithecine fossils demonstrate a pongid pattern rather than a modern hominin pattern.

5.2 Further Biological Implications of Human Language Apart from Lunate Sulcus

With regards to further biological implications of human language, the posterior parietal cortex (the region of the parietal neocortex posterior to the primary somatosensory region) contains cortical fields that determine 'the sense of self' and plan movements by coding the locations of objects both within and outside of the body frame (Krubitzer & Disbrow, 2010). Increasing the 'sense of will' in the posterior parietal lobe naturally embedded meaning and intention to language while creating structures to aid in the representation of language. The principal activity of the prefrontal cortex is thought to be the management of social cognition, which is the performance of executive functions in accordance with goals (Miller et al., 2002). Social cognition, therefore, has given humans talent for analyzing social context and situations. The temporal lobe works to interpret language, emotions, and memory (Smith, 2007) and serves to store sounds and meanings of language for possible interpretation.

Certain diseases have also helped clarify the functions of different brain regions. Broca's aphasia (prefrontal cortex damage) is a condition under which individuals know what they want to say but cannot speak the words (Purves, 2008). These patients can generally comprehend words and simple sentences but are incapable of producing fluent speech. Other problems associated with Broca's aphasia include articulating, finding, and repeating words and difficulty understanding sentences with complex grammatical structures (Friedmann et al., 2006). Specifically, patients have trouble expressing their 'free will' due to a lack of social cognitive abilities.

However, damage to posterior parietal cortex (Wernicke's area) results in fluent yet incoherent speech. In other words, the particular individual with aphasia will be able to fluently articulate words, but the spoken sentences will be meaningless (Manasco, 2014). That is, the language is spoken with social cognition but without intention.

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