Language evolution to revolution: the jump from finite communication system with many words to infinite recursive language was associated with acquisition of mental synthesis

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Keywords: Language evolution, hominin evolution, human evolution, recursive language, flexible syntax, human language, syntactic language, modern language, Cognitive revolution, Great Leap Forward, Upper Paleolithic Revolution, Neanderthal language

Abstract

There is overwhelming archeological and genetic evidence that modern speech apparatus was acquired by hominins by 600,000 years ago. There is also widespread agreement that behavioral modernity arose around 100,000 years ago. We attempted to answer three crucial questions: (1) what triggered the acquisition of behavioral modernity 100,000 years ago, (2) why there was a long gap between acquisition of modern speech apparatus and behavioral modernity, and (3) what role language might have played in the process. We conclude that the communication system of hominins prior to 100,000 years ago was finite and not-recursive. It may have had thousands of words but was lacking flexible syntax, spatial prepositions, verb tenses, and other features that enable modern recursive language to communicate an infinite number of ideas. We argue that a synergistic confluence of a genetic mutation that dramatically slowed down the prefrontal cortex (PFC) development in monozygotic twins and their spontaneous invention of recursive elements of language, such as spatial prepositions 100,000 years ago resulted in acquisition of special type of PFC-driven constructive imagination (called *mental synthesis*) and converted the finite communication system of their parents into infinite recursive language.

1. Acquisition of modern speech apparatus from 2 million to 600,000 years ago

The articulate speech of humans is unique among primates. The vocal tract of our closest relatives, chimpanzees is extremely limited in its ability to modulate sound. While there is no theoretical limit on the number of different vocalizations nonhuman primates can generate [1], attempts to teach chimpanzees articulate speech have failed [2] and the range of distinct vocalizations observed in the wild is limited to between 20 to 100[3–6]. On the contrary, human languages contain tens of thousands of different words easily generated by the modern human vocal apparatus. Paleoanthropologists study the evolution of articulate speech and the underlying vocal tract as an indicator of language evolution [7–9]. The modern vocal apparatus developed as a result of changes of the structure and the position of many organs that play a role in generating and modulating vocalizations: larynx, tongue, musculature of the mouth, lips, and diaphragm as well as the neurological control of the associated musculature. While cartilaginous and soft tissue is not preserved in the fossil record, we can draw conclusions about the evolution of vocal apparatus from the bony structures which do survive. Three lines of converging evidence point to acquisition of modern speech apparatus by 600,000 years ago: 1) the changes in hyoid bone, 2) the flexion of the bones of the skull base, and 3) the evolution of the FOXP2 gene.

1. The changes in hyoid bone. This small U-shaped bone lies in the front of the neck between the chin and the thyroid cartilage. The hyoid does not contact any other bone. Rather, it is connected by tendons to the musculature of the tongue, and the lower jaw above, the larynx below, and the epiglottis and pharynx behind. The hyoid aids in tongue movement used for swallowing and sound production. Accordingly, phylogenetic changes in the shape of the hyoid provide information on the evolution of the vocal apparatus.

The hyoid bone of a chimpanzee is very different from that of a modern human [10]. The australopith hyoid bone discovered in Dikika, Ethiopia, and dated to 3.3 million years ago closely resembles that of a chimpanzee [11]. The *Homo erectus* hyoid bone recovered at Castel di Guido, Italy, and dated to about 400,000 years ago reveals the "bar-shaped morphology characteristic of *Homo*, in contrast to the bulla-shaped body morphology of African apes and *Australopithecus"* [12]. The Neanderthal hyoid bone from about 60,000 B.C. discovered at the Kebara 2 Cave in Israel [13] is virtually identical to that of a modern human in size and shape suggesting that the last direct ancestor of both *Homo neanderthalensis* and *Homo sapiens* (namely *Homo heidelbergensis*) already possessed a nearly modern hyoid bone [14]. The similarities between Neanderthal and modern human hyoid make it likely that the position and connections of the hyoid and larynx were also similar between the two groups.

2. The flexion of the bones of the skull base. Laitman [15,16] has observed that the roof of the vocal tract is also the base of the skull and suggested that evolving vocal tract is reflected in the degree of curvature of the underside of the base of the skull (called basicranial flexion). The skull of *Australopithecus africanus* dated to 3 million years ago shows no flexing of the basicranium, as is the case with chimpanzees [17]. The first evidence of increased curvature of the base of the basicranium is displayed in *Homo erectus* from Koobi Fora, Kenya, 1.75 million years ago [15]. A fully flexed, modern-like, basicranium is found in several specimen of *Homo heidelbergensis* from Ethiopia, Broken Hill 1, and Petralona from about 600,000 years ago[18] providing converging evidence for acquisition of modern-like vocal apparatus by 600,000 years ago.

3. The evolution of the FOXP2 gene. The most convincing evidence for the timing of the acquisition of the modern speech apparatus is provided by DNA analysis. The FOXP2 gene is the first identified gene that, when mutated, causes a specific language deficit in humans. Patients with FOXP2 mutations exhibit great difficulties in controlling their facial movements, as well as with reading, writing, grammar, and oral comprehension [19].The protein encoded by the FOXP2 gene is a transcription factor. It regulates genes involved in the production of many different proteins. The FOXP2 protein sequence is highly

conserved. There is only one amino acid difference in the chimpanzee lineage going back some 70 million years to the common ancestor with the mouse [20]. The FOXP2 proteins of chimpanzee, gorilla and rhesus macaque are all identical. This resistance to change suggests that FOXP2 is extraordinarily important for vertebrate development and survival. Interestingly, there is a change of two amino acids in FOXP2 that occurred over the last 6 million years, during the time when the human lineage had split off from the chimpanzee. These two amino acid substitutions predate the human-Neanderthal split. The analysis of the Neanderthal DNA extracted from two different individuals excavated from the El Sidron Cave in Asturias, northern Spain, showed that modern humans and Neanderthals have an identical FOXP2 protein sequence [21]. This indicates that *Homo heidelbergensis,* the common ancestor of *Homo sapiens* and Neanderthals, already had a FOXP2 protein sequence that was identical to that of modern humans. The comparatively fast mutation rate of FOXP2 in hominins indicates that there was strong evolutionary pressure on development of the speech apparatus before *Homo sapiens* diverged from Neanderthals over 500,000 years ago [22].

Based on these three lines of evidence — the structure of the hyoid bone, the flexion of the bones of the skull base, and the FOXP2 gene evolution — most paleoanthropologists conclude that the speech apparatus experienced significant development starting with *Homo erectus* about two million years ago and that it reached nearly modern configurations in *Homo heidelbergensis* about 600,000 year ago [7]. We will never know the extent of *Homo heidelbergensis* neurological control of their speech, however, considering that chimpanzee communication system already has 20 to 100 different vocalizations [3–6], it is likely that the modern-like remodeling of the vocal apparatus in *Homo heidelbergensis* extended their range of vocalizations by orders of magnitude. In other words, by 600,000 years ago the number of distinct verbalizations used by hominins for communication could be on par with the number of words in modern languages.

2. Acquisition of behavioral modernity around 100,000 years ago

Archeological records from many geographically diverse areas show that around 40,000 years ago human society has experienced a sudden emergence of four novel traits, these being: 1) figurative arts, 2) manufacturing of multitude of new types of tools, 3) improvements in design and construction of living quarters, and 4) elaborate burials. Together with 5) fast colonization of the globe and migration to Australia (presumably by boats) at around 62,000 years ago, the archeological evidence indicates an abrupt change in hominin behaviour. While extreme gradualists envisage the slow emergence of "modern" behaviors over hundreds of thousands of years [23], the majority of researchers explain this abrupt change in human behavior by a single enabling event that occurred around 100,000 years ago [8,24–28].

1. Figurative arts. The archeological record possesses just a few objects that can be classified as art until about 80,000 years ago. There is always heated debate on whether some ancient item, e.g., a bone or a stone with regular incisions, is a natural artifact or was produced by a hand of a hominin [29]. The first undisputed art objects include pierced marine shells, found in various locations in Africa, Asia, and Europe, which were probably used as beads. The earliest pierced shells from eastern Morocco were dated to around 82,000 years ago [30]. The famous shells from the Blombos Cave in South Africa were dated to around 70,000 years ago, and include over 65 shells that were brought from rivers located 20 km from the cave and then pierced by inserting a small bone tool through the aperture to create a "keyhole perforation." [31,32] In addition to beads, archeologists have also discovered several ochre plaques with cross-hatched patterns engraved over a smoothed surface [33]. The plaques were dated to approximately 75,000-100,000 years ago.

The earliest figurative art appears in the archeological record around 40,000 years ago. At this point it is already represented by many different forms such as cave paintings done by charcoal and ochre or

carved into the walls, and diverse figurines, e.g., voluptuous "Venus figures," made out of bone and stone. What's interesting is that this early art appeared nearly simultaneously in hundreds of distant locations from Europe [34,35] to Indonesia [36]. Among drawings and figurines, there are composite objects such as the Lowenmensch ("lion-man") sculpture from the caves of Lone valley in Germany (dated to 37,000 years ago) [37]. The composite objects do not exist in nature and must have been imagined by the artists by first *mentally synthesizing* parts of the man and beast together and then executing the product of this mental creation in ivory or other materials.

2. Creativity and innovation. The hominin propensity for creativity and innovation can be inferred by looking at the number and quality of the different types of tools they manufactured. Researchers have been able to observe and record an extensive list of over thirty types of tools used in the wild by chimpanzees [38–40]. Most tools, such as stones used to break nuts, are used in their natural form, but there are a few tools that are manufactured by chimpanzees. For example, chimps prepare sticks for termite-fishing by trimming twigs; they also make a sort of spear for hunting bushbabies by biting on one end of a stick [41]. Hominins expanded on the chimpanzee repertoire by adding Mode One stone choppers around 3.3 [42] to 2.5 [43] million years ago. Around 2 million years ago, *Homo ergaster* added Mode Two handaxes [44]. Around 400,000 years ago, Neanderthals added Mode Three stone tools, which consisted of sophisticated stone-flakes and task-specific tools such as large scrapers created from flint flakes [44]. These tools were produced using soft hammer percussion, using hammers made out of materials such as bones, antlers, and wood, as opposed to hard hammer percussion, which uses stone hammers [44]. Neanderthals also manufactured wooden spears[45]. This list pretty much includes all the types of tools manufactured by primates before the arrival of *Homo sapiens.*

In comparison to the relative stasis of tool development by early hominins, tool development by modern humans seems to be lightning fast [7,46]. As early as 64,000 years ago humans introduced quartz-tipped arrows suggesting the development of the bow and arrow [47]; bone needles (dated to as early as 61,000 years ago) [48], musical instruments – tools for facilitating the process of producing pleasing sounds (dated as early as 43,000 years ago) [49], and ceramic technology (dated as early as 31,000 years ago).

3. Design and construction. There is little evidence of hominins constructing dwellings or fire hearths until the arrival of *Homo sapiens*. While Neanderthals controlled the use of fire, their hearths were usually very simple: most were just shallow depressions in the ground. There is almost a complete lack of evidence of any dwelling construction [50] . The arrival of *Homo sapiens*, on the other hand, is marked by a multitude of constructed structures including stone-lined and dug-out fireplaces, as well as unambiguous remains of dwellings, which all flourished starting around 30,000 years ago. These include foundations for circular hut structures at Vigne-Brune (Villerest) in eastern France, dating back to 27,000 years ago [51]; postholes and pit clusters at a site near the village of Dolní Věstonice in the Czech Republic, dating back to 26,000 years ago [52], and mammoth bone structures at Kostienki, Russia and Mezirich, Ukraine [53]. As early as 12,000 years ago, *Homo sapiens* introduced agriculture and started to build permanent villages [7,46].

4. Adorned burials and religious beliefs. The origin of religious beliefs can be traced by following the beliefs in the afterlife. Beliefs in the afterlife, in turn, are often associated with adorned burials. Therefore the development of religious beliefs may be inferred by studying the time period when humans started to bury their deceased in elaborate graves with accompanying "grave goods."

The oldest known human burial, dated at 500,000 years ago and attributed to *Homo heidelbergensis*, was found in the Sima de los Huesos site in Atapuerca, Spain, and consists of various corpses deposited in a vertical shaft [54]. A significant number of burials are also associated with Neanderthals: La Chapelle-aux-Saints, La Ferrassie, and Saint-Cesaire in France; Teshik-Tash in Uzbekistan; Shanidar Cave in Iraq [55]. However, whether or not these sites constitute actual burial sites is hotly disputed. Their preservation could well be explained by natural depositions [56]. Even if those burials

were made deliberately, the goal may have been to simply toss the bodies away in order to discourage hyena intrusion into the caves [7]. In any case, these early burials completely lack the "grave goods" that would indicate the belief in an afterlife [7].

Human skeletal remains that were intentionally stained with red ochre were discovered in the Skhul and Qafzeh caves, in Levant and dated to approximately 100,000 years ago [57]. One of the burials contains a skeleton with a mandible of a wild boar, another contains a woman with a small child at her feet, and yet another one containing a young man with a possible offering of deer antlers and red ochre [58]. While these burials are clearly intentional, whether or not they indicate the belief in an afterlife is uncertain. The ochre by itself is inconclusive evidence. For example, ochre could have been used during lifetime to protect skin from insects and the deceased could have been buried still bearing the ochre marks. The small number of "offerings" found in these burial sites may have simply been objects that fell into the burial pit accidentally. In any case, there is not enough conclusive evidence from these early burials to judge the occupants' beliefs in an afterlife.

The number of known *adorned* burials and the sophistication of the offerings significantly increase around 40,000 years ago. To date, over one hundred graves of *Homo sapiens* have been discovered that date back to the period between 42,000 and 20,000 years ago [59]. In many cases several bodies were interred in a single grave. Burial offerings were commonplace and ochre was used abundantly. Examples include: a burial in Lake Mungo, Australia of a man sprinkled with red ochre, dating back to 42,000 years ago [60]; an elaborate burial in Sungir, Russia that includes two juveniles and an adult male wearing a tunic adorned with beads and carefully interred with an astonishing variety of decorative and useful objects, dating back to 30,000 years ago [61]; a grave in Grimaldi, Italy, which contains the remains of a man and two adolescents along with burial offerings from around 40,000 years ago [59]; and a site in Dolni Vestonice, in the Czech Republic where a woman was buried between two men and all three skulls were covered in ochre dating back to 28,000 years ago [62].

5. Fast colonization of the globe and migration to Australia. Hominins diffusing out of Africa had been colonizing the Europe and Asia long before the arrival of *Homo sapiens*: the remains of *Homo erectus* have been found as far as in Spain [63] and Indonesia [64] and Neanderthals remains have been found in Europe and Asia [65]. However, both the extent and the speed of colonization of the planet by *Homo sapiens* are unprecedented. Our ancestors diffusing out of Africa around 70,000 years ago quickly settled Europe and Asia and crossed open water to Andaman Islands in the Indian Ocean some 65,000 years ago [66] and Australia as early as 62,000 years ago [67]. Migration to Australia is consistent with the use of boats by early modern humans further underlying their propensity for technological innovations.

Conclusions from paleontological evidence. Evolution of figurative arts, creativity and innovation, design and construction, religious beliefs, and steadfast colonization of the planet are highly correlated with each other in time and geography and are indisputably associated with *Homo sapiens* diffusion out of Africa around 70,000 years ago. This abrupt change toward behavioral modernity has been characterized by paleoanthropologists as the "Upper Paleolithic Revolution," [68] the "Cognitive revolution," [69] and the "Great Leap Forward" [70] (also see [7,71]) and is unlikely to be caused by acquisition of modern speech apparatus more than half a million years earlier. Rather, the sudden change in human behavior is consistent with a single enabling process causing these multifaceted behavioral changes. This enabling process may have been acquisition of lateral prefrontal cortex (LPFC)-driven constructive imagination, called *mental synthesis*.

3. Definition of mental synthesis

Mental synthesis is the conscious purposeful LPFC-driven process of synthesizing a novel mental image from parts stored in memory. Mental synthesis is neurologically different from the other key components of imagery: simple memory recall and dreaming. Unlike dreaming, which is spontaneous

and not controlled by the LPFC [72,73], mental synthesis is controlled by and completely dependent on an intact LPFC [74–79]. Unlike simple memory recall, which involves the activation of a single neuronal ensemble encoded at some point in the past, mental synthesis is a motor act that involves an active combination of two or more neuronal ensembles [80,81]. Mental synthesis is hypothesized to be organized by the LPFC acting in temporal domain to synchronize several independent neuronal ensembles [81]. Once those neuronal ensembles are time-shifted by the LPFC to fire in-phase with each other, they are consciously experienced as one unified object or scene. In this process humans can manufacture an unlimited number of novel mental images and plan their future actions through mental simulation of the physical world.

While mental synthesis is a subjective internal mental process, it has some obvious external manifestations:

1. Figurative arts. Depiction of composite objects that don't exist in nature provides some of the particularly striking examples of mental synthesis. These composite objects such as the Lowenmensch ("lion-man") sculpture from the caves of Lone valley in Germany (dated to 37,000 years ago) [37] must have been imagined by the artists by first *mentally synthesizing* parts of the man and beast together and then executing the product of this mental creation in ivory or other materials. The composite artworks such as lion-man from Germany, a bird-man from Lascaux, a lion-woman from Chauvet, and the engraving of a bird-horse-man from Hornos de la Peña provide direct evidence that by 37,000 years ago humans were capable of mental synthesis.

2. Creativity and innovation. In the absence of mental synthesis, any innovation has to come through trial-and-error. Trial-and-error is a slow and random process. One has to be lucky to manufacture an object by accident and also happen to remember the steps involved in its production. Mental synthesis, on the other hand, allows one to mentally simulate all the possible solutions to a problem, select the best solution and then mentally test multiple manufacturing processes. The lightning fast introduction of novel tools such as the bow and arrow [47]; bone needles [48], musical instruments [49], and ceramic technology [82] is consistent with acquisition of mental synthesis some time before 62,000 years ago.

3. Design and construction. Human dwellings are not built by reflex or trial-and-error. An integral part of design and construction is visual planning, which relies on the mental simulation of the process under the direction of the LPFC. There is little evidence of hominins constructing dwellings or fire hearths until around 60,000 [50]. The appearance of well-planned dwellings as well as stone-lined and dug-out fireplaces around 30,000 years ago is consistent with mental synthesis acquisition.

4. Adorned burials and religious beliefs. Religious beliefs and beliefs in afterlife are the ultimate products of mental synthesis, the result of LPFC-driven fantasy about the unknown. The appearance of adorned burials in multiple geographical locations is consistent with purposeful mental simulation into the future life of deceased individual and therefore confirm acquisition of mental synthesis before 40,000 years ago [59].

5. Fast colonization of the globe, migration to Australia, and extinction of megafauna. As mentioned above, both the extent and the speed of colonization of the planet by *Homo sapiens* are unprecedented. Our ancestors diffusing out of Africa around 70,000 years ago quickly settled Europe and Asia and crossed open water to Andaman Islands in the Indian Ocean some 65,000 years ago [66] and Australia as early as 62,000 years ago [67]. Migration to Australia is consistent with manufacturing of boats that would have required mental synthesis. The correlation of human migration with demise of the Pleistocene megafauna [83] is also consistent with mental synthesis that would have enabled mental planning essential for manufacturing of sophisticated animal traps [84].

Thus, the five novel behavioral traits exhibited by humans from the start of cognitive revolution around 70,000 years ago, those being 1) figurative arts and composite objects, 2) manufacturing of multitude of new types of tools, 3) improvements in design and construction of living quarters, 4)

adorned burials and religious beliefs, and 5) migration to Australia are all consistent with acquisition of mental synthesis sometime shortly before 70,000 years ago.

4. Mental synthesis and infinite recursive language are inextricably linked

All human languages *allow high fidelity transmission of infinite number of novel* images with the use of a *finite* number of words. The magic of using a finite number of words to communicate an infinite number of images depends on ability to conduct mental synthesis. When we describe a novel image ("My house is the second one on the left, just across the road from the red gate"), we rely on the listener to use mental synthesis in order to visualize the novel image. When we tell stories, we are often describing things that the listener has never seen before ("That creature has three heads, two tails, large green eyes, and can run faster than a cheetah") and we rely on the listener to imagine the story in their mind's eye. As Steven Pinker put it, "the speaker has a thought, makes a sound, and counts on the listener to hear the sound and to recover that thought" [85].

This ability of human languages to communicate an infinite number of novel images with the use of a finite number of words (here and later, words are understood as units of meaning, called sememes by linguists) is facilitated by flexible syntax, spatial prepositions, verb tenses, and other common elements of grammar. Consider, for example, the exponential ability of spatial prepositions to increase the maximum number of distinct images that can be transmitted with high fidelity, Figure 1. In a communication system with no spatial prepositions or other recursive elements, 1000 nouns can communicate 1000 images to a listener. Adding just one spatial preposition allows for the formation of three-word phrases (such as: '*a bowl behind a cup*' or '*a cup behind a bowl*') and increases the number of distinct images that can be communicated to a listener from 1000 to one million (1000x1x1000). Adding a second spatial preposition and allowing for five-word sentences of the form object-preposition-object-preposition-object (such as: '*a cup on a plate behind a bowl*') increases the number of distinct images that can be communicated to four billion (1000x2x1000x2x1000). The addition of a third spatial preposition increases the number of distinct images to 27 trillion (1000x3x1000x3x1000x3x1000), and so on. A typical language with 1000 nouns and 100 spatial prepositions can theoretically communicate 1000^{101} x 100^{100} distinct images. This number is significantly greater than the total number of atoms in the universe. For all practical purposes, an infinite number of distinct images can be communicated by a recursive communication system with just 1000 words and a few prepositions. The "infiniteness" of human language has been explicitly recognized by "Galileo, Descartes, and the 17th-century 'philosophical grammarians' and their successors, notably von Humboldt" [86]. This infiniteness completely depends on the mental synthesis ability. In the example of a communication system with 1000 nouns and 100 spatial prepositions, a person with mental synthesis disability will be unable to construct novel mental images according to the rules imposed by spatial prepositions and therefore will not understand any spatial prepositions. This person will be limited in his/her comprehension to the 1000 nouns. Mental synthesis disability affects significant number of persons with low-functioning autism [87], late *first-language* learners [88–91], as well as patients with LPFC damage [75,92–95].

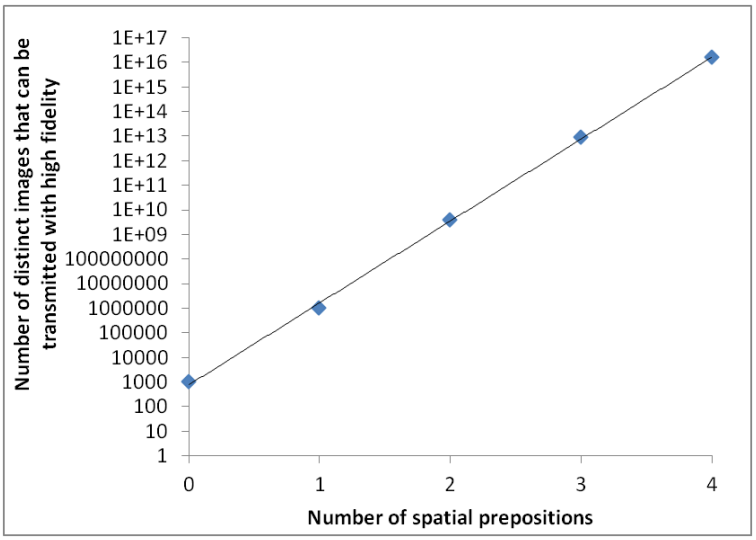

Figure 1. The graph shows the number of distinct images that can be transmitted with high fidelity in a communication system with 1,000 nouns as a function of the number of spatial prepositions.

Importantly, it is not only comprehension of infinite recursive language that depends on mental synthesis. Crucially, mental synthesis is not acquired ontogenetically unless children are exposed to infinite language before puberty [96]. According to our analysis of children linguistically isolated until puberty, finite communication systems (called kitchensign or homesign, as opposed to a formal sign language) are unable to facilitate acquisition of mental synthesis even in genetically modern children. In particular, these children exhibit lifelong mental synthesis disability as assessed by both verbal and nonverbal tests despite many years of focused rehabilitation attempts [96]. Our analysis shows that childhood use of infinite recursive language with flexible syntax and spatial prepositions is essential for acquisition of mental synthesis [96].

This results in the proverbial 'chicken and the egg' problem since neither mental synthesis nor infinite recursive language could be acquired phylogenetically one before the other. The following chapters put forward a novel theory that resolves this conundrum by proposing that the two processes – the neurologically-based mental synthesis and the culturally-transmitted infinite recursive language – were acquired phylogenetically at the same time.

5. The strange "PFC delay" mutation may have been the event that triggered acquisition of mental synthesis 100,000 years ago

Overall, humans are born with a less mature brain and develop one and a half to two times slower than chimpanzees: molar teeth erupt three years later and humans become sexually active roughly five years after the chimps do [97]. However, the period of synaptogenesis in the human PFC is stretched out over the first 3.5–10 years of childhood, whereas in chimpanzees and macaques it is limited to several postnatal months [98,99]. Furthermore, the PFC myelination rate in humans is significantly slower than in chimpanzees [100]. The delay in maturation in the PFC from a few months in chimpanzees and macaques to more than 3.5 years in humans is much more dramatic compared to this overall delay in maturation. Additionally this delay is exhibited primarily by the PFC, but not by other parts of the brain, such as the cerebellum [101]. Sometime during the past six million years a genetic mutation triggered this dramatic delay of the PFC maturation schedule. Notably, Liu *et al.* report that the delay in the PFC development occurred within the last 300,000 years, placing the "PFC delay" mutation on the radar for mutations that could have contributed to the "Great leap forward" 100,000 years ago [98].

In fact, the fixation of the "PFC delay" mutation in a human population does not make sense without a simultaneous acquisition of mental synthesis and infinite recursive language. Universally, mutations that get "selected" for and fixed in a population are associated with some survival benefits. The "PFC delay" mutation has no such obvious survival benefit. On the opposite, this mutation carries clear disadvantages to its carriers. A significantly extended immaturity of the PFC results in a prolonged childhood when the brain is incapable of full risk assessment. For example, three-year-old chimps often venture away from their mother, but rarely come close to water, their mature PFC prohibiting them from doing so. On the contrary, among human children under 4 years of age, drowning is the leading cause of death [102]. The PFC of the four-year-old child is unable to fully assess the risk of drowning. Similarly, three-year-old children cannot be left alone near fire, near an open apartment window, near a traffic road, or in a forest. In terms of risk assessment, three year-old human children are intellectually disabled compared to any other three year-old primate.

The only clear advantage of the "PFC delay" mutation is that it prolongs the "language acquisition critical period" [103] and predisposes the carrier to the acquisition of mental synthesis [96]. But this advantage materializes only later in life and only if the mutation carrier is exposed to an infinite language during his/her childhood, which, in turn, provides the experience essential for mental synthesis acquisition [96]. It follows that the first carriers of the "PFC delay" mutation must have also been the inventors and the first users of the infinite recursive language.

6. The "Romulus and Remus" theory

Who were the first people who carried the genetic mutation that slowed down the PCF maturation and invented the first recursive elements that converted their parent's finite communication system to infinite recursive language? First, in order to acquire mental synthesis they must have invented the recursive elements in their childhood, as exposure to recursive elements after puberty does not result in acquisition of mental synthesis [96]. Second, they must have spend a lot of time together, probably living under the same roof –invention of new words is common for children living together (the process called cryptophasia) [104]. Finally, both children must have carried the "PFC delay" mutation that slowed down their PFC development, extending their critical period [103] and predisposing them to acquisition of mental synthesis and infinite language. This profile of children sharing a common *de novo* mutation and living in the same family is best fitted by monozygotic twins. Accordingly, we named our hypothesis in honor of the celebrated twin founders of Rome, Romulus and Remus. Similar to legendary Romulus and Remus whose caregiver was a wolf, the parents of the real twins that lived about 100,000 years ago possessed an animal-like finite communication system. That system may have contained many words, but no flexible syntax, spatial prepositions, or other recursive elements of language. During their exceptionally (among contemporaries) long childhood the twins must have stumbled upon spatial prepositions and/or other recursive elements of language. With just a few spatial prepositions, their communication system would have become nearly infinite and therefore their normal conversations and the stories they related to each other would have provided enough stimulation to acquire experience-dependent mental synthesis [96]. We can expect that each following generation expanded the repertoire of recursive elements of language and, as a result, improved their mental synthesis. The best-studied modern example of such parallel development of newly invented language and mental synthesis is found among deaf children in Nicaragua who spontaneously developed an original sign language of great complexity, with verb agreement and other conventions of grammar [105]. As newer generations of Nicaraguan sign language speakers expanded their language, they have also improved on multiple measures of mental synthesis [88,89,91].

The grownup twins could immediately entertain the benefits of the newly acquired mental powers. They could have simulated the making of animal traps and plan an attack strategy. They would have

become more successful hunters and quickly reach the position of power enabling them to spread their genes more efficiently. A “PFC delay” mutation that would have been deleterious in the absence of a childhood exposure to infinite recursive language became a highly advantageous mutation due to the simultaneous acquisition of mental synthesis and infinite language.

7. Conclusions

In this manuscript we presented a “Romulus and Remus” hypothesis of language acquisition and proposed that recursive language elements such as spatial prepositions were acquired synergistically with mental synthesis around 100,000 years ago in one revolutionary jump towards modern infinite language. The hypothesis calls for monozygotic twins both carrying the “PFC delay” mutation that prolonged critical period for language acquisition and predisposed the carriers to acquisition of infinite language. The “PFC delay” mutation is currently found in all humans, but not found in Neanderthals [98,99]. The synergistic acquisition of mental synthesis and infinite language would have dramatically increased hominin creativity and cooperation and parsimoniously explains the “Upper Paleolithic Revolution.” Figurative art, hybrid sculptures, religious beliefs, and proliferation of new types of tools are easily explained by increased creativity made possible by the acquisition of ability to conduct mental synthesis. This event completely separated the pre-mental-synthesis hominins, who were animal-like creatures relying primarily on reflex and memory to organize their behavior, from the morphologically similar but behaviorally different breed of hominins who possessed an infinite recursive language and who relied on mental simulation to plan their behavior before actually executing it in the physical world. The acquisition of a mental synthesis resulted in what was now in essence a behaviorally new species: the first *behaviorally modern Homo sapiens*. This evolutionary synergy between speech and mental synthesis resulted in a revolutionary change in the relationship between humans and nature. The newly acquired power for mental simulation led to a dramatic acceleration of technological progress; the human population exploded and humans quickly settled the most habitable areas of the planet. The humans coming out of Africa some 70,000 years ago were very much like modern humans since they possessed both components of infinite recursive language: the culturally acquired syntactic communication system along with the innate predisposition towards mental synthesis. Armed with the ability to mentally simulate any plan and then to communicate it to their companions, humans were poised to become the dominant species.

Acknowledgments

We wish to thank Dr. Petr Ilyinskii and Mrs. Rita Dunn for productive discussion and scrupulous editing of this manuscript.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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