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Language evolution and computational capabilities: conceptualization of the first language units

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Abstract

This work addresses from the perspective of evolutionary pressure, the delicate issue of the mechanisms and causes that are behind the emergence of the faculty of language among early Homo sapiens ancestors. It mainly focuses on the motives or driving forces that are behind the emergence of the first units of language. The latter are defined in this paper, as the first vocal signals that convey information and meanings that go far beyond the usual vocal repertoire of non-human primates. They emerged as a consequence to make a sense to the principle of fairness by probing equal amounts of quantities in the context of food sharing operations after a collaborative labor. Early hominins realized that learning how to make equal food quantities, which should be regarded today as the most fundamental level for doing mathematics, is a prerequisite for the sustainability of collaborative labor (cooperation). This ancestral computing innovation is shown in this paper to be the greatest achievement of evolution in the Homo lineage. By developing the first computational capabilities, early hominins passed successfully the transition that allowed them to move from the instinct driven behavior, which prevails in the animal realm, to reasoning guided behavior in which processing information and language are two fundamental consequences.

Keywords Cognitive skills · Social behavior · Language evolution · Computational capabilities · Evolutionary pressure · Food sharing · Cooperation · Gestural communication · Vocal signals

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Abbreviations

Mya	Million years ago
ANS	Approximate number system
SFI	Sharing food into portions
AF	Arcuate fasciculus

Introduction

Among all species of the animal kingdom, none has the level of communication that would allow its individuals to plan a future, or even would allow one of its members to tell a story of the past or to predict something about the future.

Only language, a structured and codified human-made communication system (Knight et al. 2000), allows this feat. Language is a tool that enables people to cooperate to achieve goals and update information; it also provides opportunities for exchanging experiences and solving problems, in limitless proportions. With only few words, it is possible for humans to construct narrative sentences with a wide range of meanings in different scenarios, while the animal communication is often repetitive, locked in the present tense and doesn't create any new meanings (Hauser et al. 2014). Even chimpanzees, our closest relatives with whom we share nearly 99 percent of our DNA sequences (Wildman et al. 2003), can reach only an infinitesimal fraction of the human language capabilities (Hayes 1951; Gardner and Gardner 1969).

After the split of hominins lineage from that of ancestral great apes, some 6 to 7 million years ago (Bradley 2008; Suntsova and Buzdin 2020), clearly something started to move the hominins cognitive patterns to meet the ability to make stone tools on easy-to-kill prey and feed better, which allowed them to occupy the top of the food chain. They continued to develop in an unanticipated manner, shifting their social behavior in the direction of improved cooperation, which calls for thinking, sharing information, and developing strategies that inevitably conduct to the species from which the first Homo sapiens evolved. It is the only species that spread across the globe, braved the most extreme climates conditions and tried out various lifestyles, including foraging and hunter-gathering, before settling down to build cities and creating the greatest civilizations.

There are obvious distinctions between how humans and other primates lineages evolved. One may wonder what fundamental factors, in contrast to those that had relatively modest impacts on the development of non-human primates, caused human evolution to diverge significantly away from the lineages of other primates. Is this evolution associated with biological forces, or is it caused by something else, even more intricate? The theories and hypotheses of the literature on this topic do not seem to agree on the origins of language or even on the causes which would be at its origin, as they cannot base their claims on empirical data because language does not fossilize to leave archeological records that further deepen the enigma surrounding the language origins.

The origin and evolution of language has been the subject of many theories and hypotheses over the past 50 years. There are currently only two theories that can be considered dominant in the sense that they have been cited the most frequently by the literature of language evolution. The first, adept of the saltation theory, which explains that language appeared in a single evolutionary step some 80,000 years ago, is defended by the "Chomskyian school" (Chomsky 1965; Gould 1991; Chomsky and McGilvray 2012; Chomsky 1975; Hauser et al. 2002; Bolhuis et al. 2014; Berwick and Chomsky 2016) and the second has a Darwinian basis and is best represented by Pinker and Bloom (Pinker and Bloom 1990). In the Chomskyian current of thought, Gould and Chomsky have argued that human language is too complicated that it cannot follow a Darwinian evolution to arise gradually as an evolutionary process.

The second school of thought, rooted in the Darwinian principles, disagrees with this viewpoint and maintains that language is a tool that has emerged among humans to fit efficiently for survival. The capacity to communicate information about hunting, foraging, food resources, threats, and so on, provided them with a significant evolutionary advantage over their non-speaking competitors. The relation between language evolution and language acquisition, is another point on which Pinker challenges Chomsky. Indeed, Pinker and Bloom write, "language acquisition in the child should systematically differ from language evolution in the species and attempts to analogize them are misleading".

Beyond the philosophical and structural divergences that exist between these two currents of thought, one cannot deny that the controversial debate that has opposed them has strongly stimulated the investigation of empirical tools, including measures by neuroimaging technologies that have provided significant advances in understanding the brain functioning, which were clearly less sufficient at the time when Chomsky published his works than Pinker did.

However, even within the Darwinian school of thought, which maintains that language is an evolutionary development, there are significant inconsistencies between the put forth theories. Many of them, as seen in the next section, find it difficult to explain the transition to move from a communication system that is almost identical to that of non-human primates to one that is more complex and comparable to language.

In this context, the goal of this work is to address this issue and to show that language evolution underwent a dynamical thinking transition, a computational thinking-based process that propelled language to move from vocalizations carrying elementary information comparable to those of non-human primates, to the earliest building blocks of language that convey meanings, abstract information and data that are missing from non-human primates' vocal repertoire. Such a transition is shown to be in fact, part of a global behavioral transition which effected Homo sapiens ancestors when they have incremented their intelligence by passing successfully the transition from instinct-driven behavior, which predominates in the animal realm, to reasoning-guided behavior consisting in sharing and processing information out of the scope of "here and now". To make the content of this paper as accurate and reliable as possible, let me first introduce before the Method section, a Literature review section, which reviews additional theories of language, mainly those that consider language as an evolutionary extension of gestural and vocal communication. I explain in the light of the previously cited dynamical transition, why they were met by skepticism and what they missed.

Literature review

After the controversial debate that has surrounded the Chomsky saltation theory and his innateness hypothesis of language, numerous works have appeared to offer alternatives in response to objections leveled against Chomsky theories. They can be summarized in two categories of ideas: the first assumes that language is merely an extension of the gestural or vocal communication system, comparable to that seen in non-human primates. The second called "the technological hypothesis", postulates that language is an emanation from the process of learning how to make stone tools. The first viewpoint has been debated for decades, from the 70's of the 20th century until the end of the first decade of the 21th century; while the "technological hypothesis" has been subject of discussions in the past decade.

Evolutionary theories about the origins of language

Let me describe briefly the main components of the gestural theory and some elements of "the technological hypothesis".

The gestural and vocal theories

(i) According to the gestural theory of language (Hewes et al. 1973; Corballis 2010; Arbib et al. 2008), arm and hand gestures were the primary means of expression in an earlier form of human communication before words were used. According to Corballis, the shift from manual gestures to use of movements of the face and mouth could have coincided with the increasing involvement of the hands in making and using tools.

(ii) The vocal theory of language, suggests that human language evolved out of vocalizations similar to those of great apes calls, mainly guided by highly emotional circumstances, such as fights or encounters with predators (Seyfarth 2008). More details about the vocal and gestural theories are given in a recent encyclopedic reference (Gillespie-Lynch 2017).

(iii) The gossip and grooming hypothesis, is a theory about the language origins suggested by Dunbar (1996). This hypothesis is rested on the principle that the brain size expansion is assumed to have occurred throughout complex social interactions as groups increased in size. Grooming is a common social practice among most primates living in groups varying in number between one and few tens. According to Dunbar in early times, when social groups of our primate ancestors became too large, the grooming task became as tedious that it was expensively time-consuming, which makes manual grooming evolving gradually toward vocal grooming that became gossip and then language.

The technological hypothesis

In the past few years, the research activities on the origins of language have been reassessed, to come up with a new vision that involves empiricism and more of the development of cognitive functions as learning, planning, memory, reasoning, problem-solving, communication, and decision making (Chan et al. 2008) that can't be ignored in the processes that gave rise to language. This is why studies started to claim that the verbal language would be an emanation from the co-evolution between stone-tools technology and social learning (Lombao et al. 2017). Earlier, experimental studies supported by the use of functional transcranial Doppler ultrasonography, claimed that stone tool-making has implications for the evolution of human language and teaching (Uomini and Meyer 2013). Moreover, this study supports the hypothesis that aspects of language might have emerged as early as 1.75 Million years ago (Mya) when began the Acheulean technology; far from the hypothesis of the 70,000-100,000 years ago, supported by the Chomskyian school (Bolhuis et al. 2014; Berwick and Chomsky 2016).

Criticism

Although the "technological hypothesis" theory seems promising at first glance, it is nevertheless met with skepticism in the literature. One of the criticisms it faces is against its functioning, which is powerless to describe how the transition occurred from stone tool-making to speech (Cataldo et al. 2018). A significant collection of works cited in the paper of Cataldo et al., agree on the fact that "the relationships among speech evolution, cultural transmission and lithic industries still require clarification". It is also argued that the relationship between the tool-making behavior and speech is unlikely to be direct, as there is conflicting evidence as to whether spoken instructions improve tool-making learning in modern humans (Aboitiz 2018).

The above gestural theory of language has been met with the same skepticism. In his book published in 2007, the linguist R. Burling (Burling 2007) wrote that "the gestural theory has one nearly fatal flaw. Its sticking point has always been the switch that would have been needed to move from a visual language to an audible one".

What is missing from gestural and technological hypotheses?

Both gestural and technological theories present the language evolution as an observable transition between two states. The transition is regarded as a gradual move from primitive communication by gesture to verbal communication. No underlying force or mechanism, susceptible to exert an evolutionary pressure in favor of the language emergence is provided. This missing link has made these theories unconvincing.

Method

This paper attempts to address the issue of language emergence within the context of evolution by proposing a model that views language evolution as the result of an evolutionary pressure exerted by computational capabilities that only Homo sapiens ancestors were able to develop long before they pronounced the first language units. It makes use of the evolutionary time scale hypothesis, which states that the brain architecture of both Homo sapiens and chimpanzees evolved from the brain of their last common ancestor, who lived approximately 6 million years ago. While the terminal descent to Homo sapiens observed a relative brain size stasis over only 3 million years following the hominins-chimpanzees split lineages, it has gone toward a marked brain-size expansion after this date (Goodman and Sterner 2010). In chimpanzees, however, the lack of evolutionary change in some cognitive tools such as working memory during the last 6 million years ago, represents evidence of an evolutionary stasis of their brain architecture (Read et al. 2022). It is thus correct to see in modern chimpanzee's brain structures, a snapshot of what early hominin brain structures were. The differentiated distinctions that could be revealed by neuroimaging measurements of brain structures of humans and chimpanzees, can be held responsible for the huge communication gap between both species.

Based on this model, I look for social mechanisms that deal with the evolutionary pressure. I show how the human brain networks responsible for the language function, can be assumed to a biological system that has undergone an evolutionary pressure, and has been brought on by social interactions to become the complex language machine that is today.

Results and discussion

Distinctions between the brain structures of humans and chimpanzees

In the animal kingdom, each species has developed its own communication strategy so that individuals share information optimally by maximizing benefits from giving and receiving information. In most primates, vocal signals seem to be the preferred and the dominant mode of communication (Macaulay 2006). This mode doesn't seem to have evolved over millions of years. This is the case, for instance, with the chimpanzee lineage, which has gone over 6 million years without any essential evolution. While human language can recombine a small number of sounds into words and hierarchical sequences, creating an unlimited number of new sentences, the sequence generation in non-human primates seems to be strictly constrained. Chimpanzees for example can produce only 390 unique vocal sequences (Girard-Buttoz et al. 2022), which means that the vocal repertoire of chimpanzees contains only 390 "sentences".

The fact that language is able to convey such a dense amount of information indicates how much the human brain is structurally more sophisticated than chimpanzees'.

The brain network of language

In the past few decades, significant progress has been made in the understanding of language-related brain circuitry using neuroimaging. The arcuate fasciculus (AF), which connects Wernicke's region in the temporal lobe with Broca's region in the frontal lobe (Catani et al. 2004), appears to be critically important for language production (word retrieval to repetition) and comprehension abilities (Ivanova et al. 2021). While the role of Wernicke's region is to process information flow coming from the sensory association areas to make it understandable, the motor speech region, also known as Broca's area, regulates the breathing patterns employed during speech as well as vocalizations required for communication. It also coordinates the movements of the larynx, pharynx, cheeks, lips, jaws, and tongue as well as the muscles that assist respiration (Moini and Piran 2020).

Clearly, any impairment that affects one of these 3 elements of language (AF, Broca's or Wernicke's areas) would inevitably result in a language disorder. It has been shown that subcortical aphasia may have a significant underlying mechanism involving AF injury (Noh et al. 2021). Additionally, studies have recently reported the role of AF in dyslexia (Sihvonen et al. 2021).

Is there AF in non-human primates?

Recent studies related to AF analysis asked whether similar pathway exists in non-human primates? Researchers revealed (Balezeau et al. 2020) that it was clearly observed in chimpanzees, while its presence in other primate species is still subject to debate. This revelation is of paramount importance to this work, as it reveals an earlier phylogenetic origin and sheds light on its remarkable transformation over time. In another study, it has been shown that the human AF has undergone critical anatomical modifications in comparison with the macaque AF (Eichert et al. 2019).

Finally, a recent study conducted by researchers (Sierpowska et al. 2022), reveals that compared to other primates, the AF in humans has an extremely dense network of connections at the level of the posterior temporal lobe, known to be strongly involved in the language function. This study supports a finding from 2008 that showed (Rilling et al. 2008) the projection of the AF's specific terminations on the human temporal lobe (the main region involved in language skills circuits). Such projections are almost nonexistent in chimpanzees and macaques. The authors of the 2008 study support also the idea that the dense connectivity of the AF to cortical terminations underwent significant modifications over human evolution.

Memory and planning the future

Let me focus now on another crucial concept that helped differentiate Homo sapiens ancestors from other great apes and put them on the track of evolving to the human-like thinking: the capacity of thinking about the future. The ability to plan for the future is one of the greatest achievements that evolution has provided to humans.

According to neuroimaging research, the brain activity involved in recalling actual past events and picturing or modeling potential future experiences are very similar (Addis et al. 2007; Szpunar et al. 2007). In different brain areas similar levels of activity were seen during both remembering and imagining. The common "core" support to these mental activities is referred to as the default network (Buckner and Carroll 2007; Raichle et al. 2001). It is a memory-based simulation network that can flexibly connect with other networks to allow complex goal-directed simulations (Schacter et al. 2012). Recently, it has been shown (Alves et al. 2019) that the posterior section of the AF connects to the default network, indicating that it may be engaged in the mental activity of future planning.

Why can't chimpanzees learn language?

In the 1970s, the behavioral psychologist H. Terrace led an experiment called Project Nim (Terrace 2019) in order to see if a chimpanzee could be taught to use human language. In the beginning, the author thought that the chimpanzee could understand and use sentences but later he discovered that his human teachers inadvertently prompted him to reproduce hand symbols, without understanding any meaning. The Project's failure was later explained, as a failure to attempt to alter the chimpanzee's natural motivation to prefer food and other immediate rewards, rather than learning symbols.

This experiment teaches us that even the brain of our closest relatives with whom we share nearly 99% of our DNA sequences, is far to be able to produce language. According to H. Terrace "the failure of Project Nim meant we were no closer to understanding where language comes from".

How can we interpret this fatal conclusion? According to the above comparative studies, the human brain is the only biological device capable to produce language. The Broca's and Wernicke's regions, two fundamental elements in the language network, appear to be functioning coherently thanks in large part to the AF, which is not at all developed in chimpanzees as in humans. This biological barrier, among many others, makes chimpanzees unable to produce language since their evolution over millions of years didn't shape their brain for this purpose.

Additionally, how can chimpanzees process language with a brain that is one-third the size of human brain (Mora-Bermúdez et al. 2016)?

The evolutionary pressure: its origin and consequences

What has happened after the hominin-chimpanzee divergence?

After the hominin lineage split from its last common ancestor with chimpanzees, approximately 6 to 7 Mya, many cognitive and behavioral traits of humans ancestors have needed to evolve, to process information about larger, more complex and more cooperative societies that characterize modern humans (Boyd and Richerson 2009).

One can admit that at the beginning of the split, the social rules among Homo sapiens ancestors as those of food sharing, were close to that of other great apes (Foley and Gamble, 2009) and took place only in certain specific cases such as mating or defensive coalitions; otherwise sharing between non-kins is rare (Jaeggi and Gurven 2013). The mode of their cooperation in early days was also comparable to that of other primates and was negatively influenced by hierarchy dominance with the alpha males (Watts and Mitani 2002; Hare et al. 2007). Such a negative influence on cooperation, already observed in wildlife, has been evidenced in an experimental study involving cooperation and food sharing in chimpanzees (Melis et al. 2006). In this experiment, one or two packets of food are made accessible to a pair of chimpanzees only by efforts combination of both individuals. When two packets are made accessible, the pair often collaborates successfully and shares them. But if only one packet is made available, the dominant individual monopolizes the entire packet, making the subordinate unmotivated for next collaboration, which naturally kills the thinking capacity about cooperation. One may nevertheless wonder why in this experiment, when only one packet of food is made available, the food sharing operation does not occur?

The reason why cooperation does not occur is mainly due to the incapacity of chimpanzees to connect the cause and effect relationship between food sharing and future collaboration; in the sense that monopolizing the whole packet of food by the dominant individual, is an ancestral behavior inherited over millions of years and is viewed as more profitable than sharing it. Because chimpanzees have a brain that is one-third the size of human brain (Mora-Bermúdez et al. 2016), it is therefore, not sufficiently developed and equipped cognitively speaking, to process information about sharing that can be viewed as an investment, defined as a plan of resources allocation, with the expectation of a positive and sustainable benefit in the future. Thinking about relationships involving complex and abstract events occurring at levels located outside of the “here and now”, requires cognitive capabilities that can be found only in humans (Macwhinney 2005). As seen in the previous subsections relative to *“AF in non-human primates”* and *“planing the future”*, one of the reasons why chimpanzees are unable to analyze and link current experiences to the future is the low density of AF connections with cortical areas in their brain.

So, in non-human primates the instinct-based thinking strategy does not seem to have evolved over time due to the constant and primitive nature of their social organization, caused essentially by their limited cognitive resources and their weak communication skills. This study evidences that the alpha-dominance hierarchy tends to annihilate collaborative foraging (Tomasello et al. 2012) and deprives the concept of cooperation of any meaning. One can therefore assume that the level of cooperation in early humans was also impaired by nearly similar dominance.

However, by launching a cognitive revolution to transition from great apes' lives to those of Pleistocene cooperative foragers (Sterelny 2016), Homo sapiens ancestors were successful in negotiating a transition towards more developed cognitive abilities. This was the consequence of an unexpected event in the human lineage evolution that occurred when certain individuals started refusing the hierarchy dominance by disengaging from foraging and collaborating with those from whom they receive unfair returns and went selecting partners based on their previous history of tolerant sharing (Melis et al. 2006). Individuals who engaged in this social practice would bring about a new social model, which had never been practiced before, by any group of primates. It was the tipping point that would select a new generation of individuals who developed a new social model which was no longer governed by the habitual law of domination, but rather by collaboration and resources sharing.

The emergence of this type of behavior defined a new paradigm that is linked to sociology by the principle of critical mass that represents the smallest number of individuals, whose support to new social trait is necessary for successful change, which leads to significant unintended consequences for a large group (Schelling 1978). Once the critical mass of individuals refusing domination has been reached, which means the tipping point has been reached, the growth and the development of the new social model became irreversible. Such a behavioral model, more efficient than those of other primates, made it possible to move from instinct-based behaviors to the favor of reasoning rested on thinking, collaborating and sharing. By doing so, they process better their environment information to draw more resources profits in less time, with costs always less and less expensive.

Building cooperation norms

Cooperation has succeeded in ensuring the cohesion between individuals living in groups, which makes it possible to increase individual and collective returns, as enhancing success in hunting large game for example, which provides enough meat to be shared among the entire community (Kelly 1995). However, cooperation may also be damaged or even annihilated if the fine balances among three of its motives are not taken into account and respected: (i) providing for the needs of individuals involved in cooperation; (ii) identifying and putting under control harmful behaviors (as cheating) to cooperation; (iii) managing and solving protests and conflicts within social groups against what is deemed insufficient or unfair returns. Such balances were determinant in drawing the route of what cooperation should be, either permanently evolving and perfectible as in humans, or moderately stable as in non-human primates. Consequently, cooperation, which is a very widespread social interaction, observed in many animal taxa, has evolved and became so highly dense and intense in the human species (Melis and Semmann 2010; Burkart et al. 2014) that it exceeds any that we know compared with other species. Early humans have understood from the early days that cooperation can provide to each individual more benefits than he could pay in costs (Vale and Brosnan 2017). In other words, they have discovered the early win-win strategy: by cooperating they are able to achieve goals that are unreachable while working alone. To be sustainable, social cooperation must operate on the model of institutions that are able to recognize productive individuals from cheaters, those who are not motivated in paying the cost of the resources they consume. Consequently, identifying and keeping under control cheaters was one of the challenges that cooperation had to face to avoid their proliferation and cause the cooperative-institution bankruptcy. This progress was probably another critical point in the human evolution, which swerved in the human ancestors, the move to the way of formulation of general norms of social conduct and the emergence of social institutions regulating this conduct (Bowles and Gintis 2003). Later, they succeeded to build up socially structured rules for distributing the collaboratively acquired resources, which made their collaboration sustainable over time (Tomasello 2016). Such a type of cooperation, based on information processing and learning, was determinant in engaging earliest humans on the route of the cognitive revolution, which is defined here as reasoning to find solutions to problems, particularly those that are grounded upon individuals' preferences and expectations, among which equity and fairness. Making equity between individuals, is the same thing as to assess whether payoffs commensurate or not with efforts spent in foraging, which is also the capability that recognizes whether outcomes are equitable or not (Brosnan 2011).

First consequence: the brain enlargement

The brain expansion in hominins was mainly due to the growth of two substances: gray and white matter. The gray-white matter ratio is not random since it is used to identify brain damage in comatose patients after cardiac arrest (Oh et al. 2021).

In early Homo sapiens ancestors, the brain size expansion is believed to be the main factor that drove the transition in hominins, from great apes lives into those of Pleistocene cooperative foragers that occurred in two steps. First, the appearance, on the evolutionary scene nearly 2.5 Mya, of Homo habilis, the first hominin attributed to the genus Homo, and one of the earliest tool-making hominins. His brain averaged 650 cc; while many species of bipedal hominins at that time, had brain sizes in the range of modern chimpanzees around 400 cc (Coolidge and Wynn 2016). This period which nearly coincided with the prevalence use of earliest Oldowan stone tools (Braun et al. 2019), has favored the gradual spread across Africa of the tool-making industry, which was naturally accompanied by social learning (Hovers 2012). The second step occurred some 500-700 thousand years later, when another more efficient and more sophisticated technology emerged: the Acheulian handaxe technology. Its author is Homo erectus who evolved out of an earlier hominin nearly 2 Mya and had a brain size of nearly 950 cc (Rightmire 2013; Coolidge and Wynn 2016).

The emergence of the Acheulian technology nearly 1.8 Mya, is another consequence related to large brain expansion in the Homo sapiens lineage, mainly observed in Homo erectus (Lepre et al. 2011). This expansion has been followed by significant changes in brain connectivity and functionalities and is believed to have augmented the social and technical intelligence of early humans. It also might have been the basis for the ability to imagine future outcomes, such that cooperation could still be stable (dos Santos and West 2018). These arguments seem coherent with our previous analysis about the experimental study involving cooperation in chimpanzees (Melis et al. 2006), concerning their inability to perceive the causal relation between food sharing and future collaboration.

Second consequence: the cognitive devices refined by aversion to inequity

The serial increases in hominins brain volume from 400 cc to 650 cc and then to 950 cc, are the result of an evolutionary pressure, driven by a force that can be defined only by a social context radically distinct from that of chimpanzees. Indeed, many studies have suggested that cooperation and aversion to inequity evolved in parallel paths (Fehr and Schmidt 2011; Brosnan 2006, 2011). Often, the feeling of inequity awakens in individuals a mechanism that tends to compare their income to that of others, when they perform collectively a task (Vale and Brosnan 2017). Therefore, having the sense of inequity or having feelings of unfairness is that it might allow individuals, in some cooperative contexts, to recognize when they are being cheated into receiving less than they should from the collected loot (Brosnan and Bshary 2016). However, observing that the value of an income is less than it should be worth, cannot come from nothing, but requires mental skills that must be built because they don't exist in other species, including primates. Consequently, the acquisition by human's ancestors of the faculty to assess, how much two (or more) quantities are dissimilar, was a major mental advance that had huge implications on their social evolution. This has required the development of some cognitive devices, not possessed by great apes, whose efficiency have been steadily improved by experience as they played a key role in stabilizing cooperation during the human evolution (Tomasello 2016; Engelmann et al. 2017). One among cognitive skills that recognize inequity is the sense of comparison, which is used in various decision making processes. It involves the associative reasoning that operates by grouping objects with other objects that are most similar (Sloman 2002). Comparing things is the way to know how much they are dissimilar. If their dissimilarities are not perceptible, they are considered as similar, else they are unequal. If the things in question represent shared portions from collected food items, they should be considered respectively as fair and unfair returns. Today, our ability to discriminate unequal quantities is considered as an almost innate ability, since it has been the subject of many studies and has already been observed in newborns (Strauss and Curtis 1981; Izard et al. 2009). It relies on the approximate number system (ANS), which refers to our cognitive system that allows evaluation of the magnitude of quantities and collection of objects without using language (Gallistel and Gelman 1992; Dehaene 1998). The accuracy of ANS improves with age from childhood, and reaches its mature level of nearly 15%, which means that an adult can discern without counting, two collections of objects containing 100 and 115 items (Sousa 2010). In addition, we are also equipped with a sense that allows the evaluation of geometric distances when traveling from one point to another through different paths. Our intuition based upon our sense of comparison is generally able to identify without any measurements of which one is the shortest. These useful cognitive devices allow us to minimize the expenditure of our energy.

Third consequence: development of the basement of the brain language network

It is obvious that social interactions, which at the individual level are primarily controlled by brain cortical networks related to vision (gathering visual information), gestures (gestural execution), speaking (expressing verbally emotions), and hearing (gathering sound information), must be processed simultaneously and cohesively. This role is completely carried out by the AF, which connects the frontal, parietal, and temporal lobes (Catani and de Schotten 2008). The AF is the first brain structure to be asked to transfer information between brain regions, to be processed, when social pressure is applied to an individual. Since the earliest hominins used reasoning more than other primates did in their social interactions (cooperation management, sharing of food and knowledge, equal amounts of probing, etc.), this may help to explain why the AF of modern humans has undergone significant anatomical changes in comparison to those of other non-human primates (Eichert et al. 2019). This may also explain why compared to other primates, the human AF, which is considered here as the basement of the language circuitry, has an extremely dense network of connections at the level of the posterior temporal lobe (Sierpowska et al. 2022).

Language, the tool that makes concepts understandable and spreadable

The brain networks of early hominins evolved over time to a structure that allowed the development of primitive reasoning about abstract concepts, such as remembering past events, remembering shortest paths between locations, planning for the future, and many other things of everyday life. Such capabilities require inevitably updating and exchanging information. As a consequence, communication between them needs to evolve to meet everyday challenges. For this reason, language underwent multiple stages of complex and dynamic advancements (Dunbar 2017; Morgan et al., 2015), over at least hundreds of thousands of years. In this section, I am interested in presenting its very early stages because they are the hallmark of early human-like thinking (Putt et al. 2017). I ask: what were the causal motivations that triggered language's emergence, and what were the first vocal units that met the definition of language which convey information and meanings that go far beyond the usual vocal repertoire of non-human primates?

The emergence of the first units of language

Unlike the "technological hypothesis" that deals with production of stone tools, which concerns only an elite subset of a social group; other social concerns such as resources sharing norms, can occupy a higher position in the hierarchy of social preoccupations because they affect everyone in society. In early humans, after a food sharing operation for instance, nobody can be indifferent to the amount of food that he can receive in comparison to others'. Consequently, the mass of individuals concerned with the techniques of resources sharing is much greater than by tool-making techniques. Today, one can still draw the same conclusion. Resources-related issues, such as food safety, food production, and food management, including the expertise in the sharing operations, are strong stimulants for conveying in the community, feelings and motives behind agreements or protests.

The scenario I present here simulates how the first bricks of language appeared. To do this, I aim to make visible the bridge that connects the intention to communicate within a social network to complex and abstract concepts that are based on mental representations of scenes that are not limited to the "here and now". The core of this approach is believed to be strongly tied to the food sharing techniques which have played a major role in finding the social equilibrium in communities. The growing expertise over time of these techniques became one of the major sources of inspiration on which the human computational knowledge has been built.

For both modern humans and their ancestors, food safety has always been a significant social concern. One of the factors that can ensure its sustainability is the management of its production and redistribution. Sharing food in early humans was an almost daily activity and occurred often after collaborative foraging and hunting task. It was a sensitive operation that had certainly required some expertise issued from a set of cognitive skills. Its failure would have had serious social damages as conflicts issued from dissatisfaction and could break the balance that supports the sustainability of the group, if individuals feel that their incomes should be higher than what they receive. Sharing resources fairly has always been a universal and timeless challenge in societies, as it has crossed all ages to become an essential argument in most modern public policies. If these fail, there will be social unrest, disruptions, and conflict (Velasquez et al. 2016). So, its expertise began in earliest communities, when food sharing came under the pressure of looking for fairness, as protests had become frequent and vehement if done in an unbalanced manner. Early humans quickly realized that the expertise in this area was a precious prerequisite for cooperation sustainability and social stability. Behind protests against what was considered unfair, actors were demanding compensation that reduced the dissimilarities between incomes. But how to do that, to express for the first time, an abstract concept that does not yet exist, as the shared quantities to be equal (fairness); in a context where this concept is symbolically and semantically non-existent, at a time when language is almost non-existent or not yet practiced? To make the concept of fairness comprehensible and potentially spreadable in the majority of the community, it became necessary for early humans to show their disagreement through gesture and vocal expressions, when incomes related to food sharing were excessively unequal. Consequently, the concept of equity (fairness) has become a tool to consider and to conceptualize. Practically, fairness consists in subtracting an amount of food from large portions to move to smaller ones; and semantically, appropriate vocalizations started to be used to make it understandable.

Over time, competition between vocal and gestural cues in early humans, has selected the former according to studies (Burkhardt-Reed et al. 2021; Fröhlich et al. 2019), which suggest a gradual change in modality, from a gestural communication to predominantly vocal communication. The reason why fairness became acceptable is that it is a principle that makes sense to equity, often needed by a majority, except perhaps cheaters, those who want to take advantage from the ignorance of others. The acceptability of the fairness principle seems to be aligned with Rawls Theory of Justice (Rawls 1971). In his theory, Rawls asks us to imagine ourselves in a situation in which we have to make a choice, behind a veil of ignorance, between a fair society (of equality) and another without knowing what gender, race, abilities, tastes, wealth, or position we would have. Rawls claims that most of us would choose “fair”.

The principle of fairness has originated when human ancestors began to live in groups, motivated by cooperation and resources sharing. It was the day these ancient ancestors realized that without equity, the law of dominance would inevitably replace the law of cooperation, which would result in everyone’s losing.

The scenario I describe here is one of the keys to understanding the dynamics and evolution of the transition of communication from the emission of vocal signals (as do non-human primates), to the transmission of units of language, which convey information containing ideas, principles and abstractions. Once this scenario started to work, communicating by using rudimentary units of language easily spread to other communities (Montanari and Saberi 2010), and became a generalized mean of communication.

In a relatively recent paper, researchers (Dyble et al. 2016) have reported the results of a study on the food sharing networks of two contemporary groups of hunter-gatherers: the Mbendjele of the Republic of Congo and the Agta of the Philippines. The work in question reveals surprising similarities in the food sharing methods, although these groups are separated by thousands of kilometers of land and ocean from each other. The similarities consist in dividing the food production into a certain number of packets, according to their caloric values that are then distributed among three-tiered social network in each group so that the protection of individuals is ensured from hard times, when food becomes scarce. The same similarity has already been observed and reported by Yellen 45 years ago (Yellen 1977), among another population of hunter-gatherers, the !Kung in southern Africa. These similarities are so fine that they can’t be the result of coincidence. The most plausible explanation to such a troubling similarity is that all these groups have skillfully inherited their respective food sharing practice from a common Homo sapiens ancestor, long before he started to migrate from the African continent to Southeast Asia and elsewhere in the world. Only oral transmission i.e. language can convey the precision of principles found in the sharing operation described in these works (correlation between number of food packets and number of individuals). One can therefore postulate that language has been practiced long before earliest humans’ migration out of Africa.

Fairness, in short, appears to be one of the X words that early humans used to begin their speech.

The insatiable three-part cycle for knowledge advances

It is believed that the default mode network, in which AF is deeply anchored, serves as the hub of human creativity (Bashwiner et al. 2016). The AF, cortical sensorimotor areas, and the default network are all involved in the ability to develop

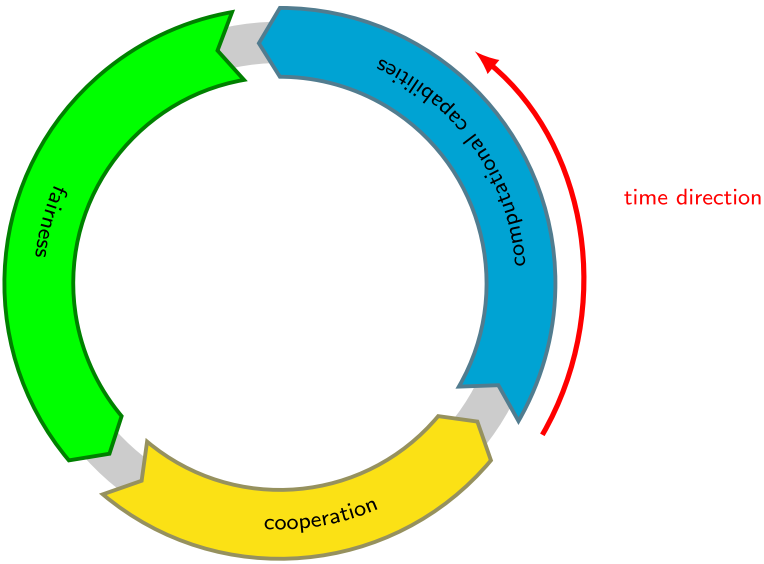

Fig. 1 The three-part cycle of endlessly progress of knowledge. In earliest humans, three social interactions work together as time passes, so that each element feeds on and reinforces each other. Cooperation feeds on fairness (equity), as it increases incomes per individual that makes the community even more motivated for stronger and more complex cooperation. Fairness feeds on computational capabilities that conceives the expertise, which allows producing more equity between the community members that enhances satisfaction and impacts positively cooperation; while computational capabilities, feeds on more intense and more complex cooperation that requires increasingly demanding levels of expertise to make fairness more accurate

more innovative skills through social interactions such as learning, sharing, updating information, and producing creative work. Over evolution, the creativity goes towards communication refinement, which invented computational capabilities and fairness and then language. These three elements became unconditionally tied within a three-part insatiable cycle, in which each element feeds on and reinforces each other, making the human knowledge endlessly advancing.

The cycle works in a ceaseless way as follows: cooperation feeds on fairness (equity), as it increases incomes per individual that makes the community even more motivated for stronger and more complex cooperation. Fairness feeds on computational capabilities that conceives the expertise, which allows producing more equity between the community members that enhances satisfaction and impacts positively cooperation; while computational capabilities feed on more intense and more complex cooperation that requires increasingly demanding levels of expertise to make fairness more accurate. This cycle, shown in (Fig. 1) which never seemed to have ended working since humans' earliest days, has put their reasoning skills on a non-ending upward slope.

This cycle that made humans cognitive skills more and more efficient, seems on the other hand, to be failing among non-humans primates, with regard to their modest cognitive evolution over millions of years. Cooperation, which does not feed on fairness, seems to be the cause of its failure.

Fig. 2 Quantity Q of meat, shared into n equal fractions in Mbendjele hunter gatherers. Each portion x of meat, is the solution of the equation Q=n.x (Wikimedia Commons)

The rise of vital algebra

Humans and their ancestors have sought justice in all situations from the beginning of time till the present. However, fairness requires knowledge of evaluating quantities and making judgments about their similarities and differences. Equal fractions are one of the earliest abstract concepts that were essential to realize fairness. Fraction is an abstract data type that represents just a fragment of one whole thing. By manifesting their aversion to inequity, earliest ancestors of Homo sapiens demanded for satisfactory solution in the food sharing problem that consisted in dividing the loot of their foraging operations into equal fractions.

Through fairness, early humans were actually asking for the resolution of the mathematical problem that finds the solution of one equation with one unknown. Indeed, if the spoils represents a quantity Q of food, which must be divided into n shares corresponding to the number of individuals involved in the sharing, then the "fair" income x of each actor should be given by the fraction $x = Q/n$. The concept behind this "mathematical formula" was already known to hunter-gatherer ancestors, long before the appearance of the algebraic formalism that we use today. The image[1] of Fig. 2 illustrates meat sharing operation in the Mbendjele modern hunter gatherers of the Republic of Congo, a community cited previously in the work of Dyble et al. (2016). This vital meat sharing operation that aims to find the share x due to each actor, meets exactly the definition of equation solving and is made neither with any calculation, algorithm nor with the use of weighing scales and yet seems fair.

Consequently, the concept of fraction and equation solving were not born for the first time, as it is generally believed, when earliest algebra equations and the Arabic numerals algorithms of the rhetorical algebra, made their appearance some 1200 years ago; but appeared much earlier when aversion to inequity made human's ancestors asking for equal fractions of their spoils. In this context, "equal fractions"

1 Reprinted from: https://upload.wikimedia.org/wikipedia/commons/3/3f/Mbendjele_meat_sharing.jpg.

appears as an object of great significance only if it aligns with numerous cognitive skills that must work together in a highly integrated and complex manner, including computational abilities, sense of comparison, items counting of food and individuals, aversion to inequity, construing sense of equity, memory of expended effort, social context analysis, and so forth. It is only when these data are being cohesively processed that associated vocalizations match the condition that makes them eligible to be language units, carrying feelings and abstract information that possesses intelligible meaning. If all these conditions are not fully satisfied, the practice of language would have no meaning. Only the human brain is shaped for such a feat.

The enigma of Sharing Food Into Portions (SFIP)

Sharing food in modern hunter-gatherers varies from one culture to another, from one continent to another but always obeys to the same rules. They first divide the spoils of their collaborative foraging into separate units of food on the scene, which are then brought back to a central location and shared, even with non participants to the foraging operation (Yellen 1977; Enloe 2003; Gurven 2004).

To my knowledge, chimpanzees and other great apes societies have never been observed to practice such a method of food sharing. As with toolmaking and language, humans are the only species that divide food into portions before distributing and consuming it. I have found no references in the literature that report food division in packets in the wild. Social predators as lions, wolves, African wild dogs and hyenas, share their food by feeding on the carcass directly (Jordan et al., 2022) in a priority order that obeys social rules and hierarchy status of each individual. Who among our ancestors developed the idea of dividing food among people in portions before consumption, and how long ago did this practice begin? Why other non-human primates do not share food in this manner is another perhaps even more complicated question.

Why do only humans practice SFIP?

Food packaging requires skills in tools making as butchering tools, plus an advanced level of cognitive and computational capabilities not possessed by other primates. The packaging operation is supported by complex mental skills, which consist of correlating coherently two variables: the number of food portions to the number of individuals (or households) who benefit from them, which necessarily calls advanced cognitive capabilities allowing their association. Even if this operation occurred at a time when our ancestors did not know how to count items, they certainly circumvented the problem of counting since counting is a “modern” human invention. In addition, making shared portions to meet specific requirements that define their respective sizes, was another cognitive challenge that humans’ ancestors had to meet. In clear, packaging food seems to be a set of complex operations, particularly if humans ancestors’ diet was varied and similar to the diet of modern chimpanzees: omnivorous, including fruits, leaves, flowers, bark, insects and meat (Andrews and Martin 1991; Milton 1999; Watts 2008).

When did SFIP start?

Several studies evidenced meat consumption by hominins about 2 Mya, with the first occurrence before 3 Mya in East Africa (McPherron et al. 2010; Thompson et al. 2019). Stone tool butchery marks on ungulate fossils in several African archaeological sites demonstrate a significant level of meat consumption by Pleistocene hominins (Domínguez-Rodrigo et al. 2012). Oldowan stone tools designed for butchering animals, dated to 2.4 million years ago, were also discovered in Northern Africa in Algeria (Sahnouni et al. 2018). Excavated fossil bones from the same site show stone-cut marks produced by the associated tools. These studies show that using tools to remove quarters of meat from animal carcasses, is a practice that dates back to at least two millions of years among humans' ancestors. The skills of cutting animal carcasses into pieces were quite advanced at that moment for at least two reasons: (i) to avoid competition with other predators, (ii) to make easier its piece-by-piece transportation. This function was mainly fulfilled by the Oldowan tools that were also used to remove flesh and pound bones to obtain marrow (McPherron et al. 2010; Diez-Martín et al. 2015). The appearance of the Acheulean technology some 1.7 Mya, which roughly coincides with the emergence of Homo erectus (de la Torre 2016), is one of the hallmarks of major transitions observed in the human evolution. It is also believed that the emergence of the Acheulian technology is closely related to significant expansion in the evolution of the human brain size that enabled additional cognitive and technological advancements (Gowlett 1986; Klein 2009). Although the purpose of the early functionalities of the first Acheulean assemblages remains unclear (Diez-Martín et al. 2015; Lepre et al. 2011), one can believe with respect to their refinement that they emerged to make the cutting of soft tissues more accurate, and to make it possible to obtain pieces of meat of different sizes. Acheulean tools are more suitable in processing carcasses and more accurate in the meat sharing operations, compared to Oldowan hammerstones. Therefore, it is not excluded that all of the cognitive and material prerequisites for sharing food into portions were satisfied at this time.

In social interactions that led to SFIP, there were certainly vocal units that met the definition of language as mentioned previously. Consequently, the emergence of the Acheulean technology is probably the signature of the appearance of a rudimentary form of language (earliest units of language). Nonetheless, it was sufficiently advanced to convey abstract meanings that went far beyond vocalizations of other primates.

Conclusion

In most primates' societies, the social rules are dictated by the law of dominance. After experiencing this social model, ancient Homo sapiens ancestors engaged in a complex process of developing computational capabilities. This has been triggered by a category of individuals who rejected hierarchy dominance while receiving unfair incomes after a collaborative labor, and selecting partners based on their previous history of tolerant sharing. By doing so, they sowed the seeds that would one day grow to give the word that means "fairness". It was the day that these distant ancestors realized that without equity, the law of dominance would inevitably replace the law of cooperation, which would result in everyone's losing.

Such a desire for fairness led Homo sapiens ancestors to process information of their environment that consists in measuring, counting, and analyzing quantities of things with which they interacted.

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