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ORIGIN AND DEVELOPMENT OF HUMAN COGNITION. EXAPTATION, COEVOLUTION AND COGNITIVE EMERGENCE.

Origen y desarrollo de la cognición humana. exaptación, coevolución y emergencia cognitiva.

Origem e desenvolvimento da cognição humana. Exaptação, coevolução e emergência cognitiva.

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R E S U M E N

Los mecanismos psicobiológicos por los que el género Homo desarrolló sus capacidades cognitivas se han centrado en la genética evolutiva y la acción de su particular medio ambiente social y cultural, pero su concreta articulación aún dista mucho de conocerse. En este estudio se analiza cómo la cultura de los nichos humanos adquiere un protagonismo muy importante en el desarrollo cognitivo de las poblaciones humanas. Los mecanismos culturales y sociales utilizados para lograr el desarrollo de sus capacidades cognitivas e incluso el inicio de otras nuevas serían la exaptación, coevolución y emergencia. Como ejemplo de esta forma evolutiva se propone un análisis de la cognición causal.

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A B S T R A C T

The psychobiological mechanisms by which the genus Homo developed its cognitive abilities have focused on evolutionary genetics and the action of its particular social and cultural environment, but their concrete articulation is still far from being known. This study analyses how the culture of human niches takes on an especially important role in the cognitive development of human populations. The cultural and social mechanisms used to achieve the development of their cognitive capacities and even the beginning of new ones would be exaptation, co-evolution, and emergence. As an example of this evolutionary form, an analysis of causal cognition is proposed.

R E S U M O

Os mecanismos psicobiológicos através dos quais o gênero Homo desenvolveu suas capacidades cognitivas estão centrados na genética evolutiva e na ação de seu particular meio ambiente social e cultural, mas sua articulação concreta ainda está muito distante de ser conhecida. Neste estudo analisamos como a cultura dos nichos humanos adquire um protagonismo muito importante no desenvolvimento cognitivo das populações humanas. Os mecanismos culturais e sociais utilizados para alcançar o desenvolvimento de suas capacidades cognitivas, inclusive o início de outras novas, seriam a exaptação, a coevolução e a emergência. Como exemplo desta forma evolutiva foi proposta uma análise da cognição causal.

Introduction

The evolution of human cognition is the process that will most characterise us as an eminently cultural species. However, its development in the genus Homo presents great theoretical gaps about the mechanisms that made it possible. Its study requires the elaboration of interdisciplinary methodological forms, which can diminish the scientific subjectivity of the theoretical hypotheses in which, for their elaboration, they obviated the existing information in the sciences that were not used. The importance of interdisciplinarity is justified by the need for a theoretical synthesis from different sciences, starting from a multidimensional conception of phenomena, as well as the recognition of the relative character of the separate scientific approaches (Piaget et al. 1973). The creation of an appropriate, broad, and well-coordinated interdisciplinary approach will provide a better scientific basis for the hypotheses which, with their particular method, can be developed. In this context, it seems that at least the more specific disciplines of the study of human cognition should be used, such as evolutionary biology (genetics, embryology and epigenetics), neurology (functional anatomy, neurological physiology, paleoneurology) and sciences about human society and culture (archaeology and social anthropology) and cognitive sciences (psychology and linguistics).

The coordination of these sciences will form the theoretical basis on which this work will be developed, as their understanding will give us the keys to the complex cognitive evolution of our lineage.

1. Human evolutionary biology

Any method that we can develop for the study of human societies in all their contexts must begin with the understanding of their neurological and cognitive evolution, since without a minimum theoretical base in this respect we can only make hypotheses of limited foundation. As we learn more about the evolutionary mechanisms of the human genome, it is increasingly important to assess both genetic variation and environmental and cultural contexts in human evolution (e.g., Heyes, 2012; Creanza et al. 2017).

Evolutionary biology is therefore a fundamental basis for all processes related to human cognition. Thus, genetics, epigenetics, and embryological aspects provide us with the physiological conditions that will shape the development of cognitive capacities. The advances in genetics indicate the different action of genes, as it distinguishes between structural genes and regulators, controllers or Hox. The action of the latter regulates the activity of the former in time and rate of action of the embryological process. The mutation of the Hox genes will give rise to heterochronies, producing embryological alterations with important and relatively fast evolutionary repercussions (Gould & Lewontin, 1984; Churchill, 1998; Bogin, 1999). However, the action of these genes can be influenced in turn by epigenetic processes of various kinds (Saetrom et al. 2007; Vaissiére et al., 2008; ENCODE, 2012; Gokhman et al., 2014). Likewise, its genetic manifestation could be affected by embryological processes that we know as morphological cascade changes (Sinha, 1996).

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In the neurological evolution, the action of regulatory genes or Hox (heterochrony) in the cortex had special relevance, especially in the areas of associative character. Some of them act in the production of folds or gyrification of the cerebral cortex, notably increasing its functional surface (Rilling & Insel, 1999; Cela Conde, 2002). This is the case of the ARHGAP11B gene (Florio et al. 2015); the TRNP1 gene with its participation in the control of the tangential and radial expansion of the cerebral cortex (Stahl et al. 2013); the SRGAP2 gene and its successive mutations related to the neocortical development and neuronal plasticity favouring a greater number of connections between neurons (Dennis et al. 2012); and the most recent NOTCH2NL related to the increase of the cortex in different areas (Fiddes et al. 2018; Suzuki et al. 2018). These genes mediate in the transcription factors that initiate and/or stop the developmental processes carried out by other genes, such as controlling the time of creation of proliferative units in the embryological formation of the cortex (Allman, 1990; Rakic, 1995; Finlay et al. 2001; Rakic & Kornack, 2001). These evolutionary actions bring light to the increase of the functional cortical surface and the most synaptic capacity, with an allometric and quantitative character, in the sense of higher and better functional activity (Florio et al. 2015, 2016).

The increase in the surface of the cortex is accompanied by a greater synaptic potential that allows the creation of neuronal networks with a cognitive content, with a greater capacity to process information (Semendeferi et al. 2002; Florio et al. 2015, 2016). This increase in neuronal interconnectivity requires mechanisms that ensure and accelerate information transmission, such as the process of myelin coating of neuronal axons or broad and late myelinization (Rilling & Insel, 1999; Semendeferi et al. 2002; Schoenemann, 2006; Gómez-Robles et al. 2015).

2. Functional structuring of the brain

Neurological functionality is manifested through the creation of neural networks (connectome) as the basis for storing and processing information. Their organisation will follow the guidelines of a hierarchical or functional structuring of the cortex that will depend on the neurological physiology itself, which indicates that it will go from the simplest (reception of sensory stimuli) to the most complex (creation of complex behaviours). The process would begin with the arrival of the sensory afferences to the primary areas, constituting innate functional protomaps or sensory homunculi, although they would later be remodelled by the continuous external afferences. At the same time, there is another motor homunculus from which the motor commands for the relevant behaviours would emerge (e.g., Boltz et al. 1990; Kandel et al. 1995; Rakic, 1995). Within this complexity, the primary sensory areas (visual, somatosensory and auditory) would be connected to other adjacent cortical centres or secondary association areas, receiving the information with some elaboration carried out in the primary ones; these would be connected to the tertiary association areas that would receive the more elaborated information from the secondary ones, and all of them would carry out the functional connectome of the brain (Luria, 1966; Kandel et al. 1995; Sepulcre, 2014). This hierarchical structure means that the formation of neural networks is arranged in an ascending order of complexity, in their task of creating the different neural networks that will support the various cognitive functions.

In this context, it should be remembered that the allometric changes occurred mainly in the more complex or associative cortical areas (Florio et al. 2015), which are specialized in the processing of information, and this must have repercussions on their functional capacity (behaviour). However, this development must be completed by the qualitative increase of the cortex, which would be very dependent on the afferences they receive from the environment. Neuronal plasticity (Kandel et al. 1995; García-Porrero, 1999; Gómez-Robles et al. 2015); neuronal death or pruning in the early stages of life of sparsely used neurons after birth (Petanjek et al. 2011; Gómez-Robles et al. 2015); a broad and late myelinization that favours rapid neurological transmission (Miller et al. 2012; Bercury & Macklin, 2015); and the existence of a critical period after which cognitive structuring would be much more difficult or even impossible to perform (Grimshaw et al. 1998; Gómez-Robles et al. 2015) are neurological processes that indicate the brain's dependence on environmental afferences for adequate cognitive development (Belinchón et al. 1992; Grimshaw et al. 1998; García-Porrero, 1999; Gómez-Robles et al. 2015). Therefore, the processing of the information that reaches the brain is based on the organisation of highly complex, multifunctional, and hierarchically structured neuronal networks and circuits, forming the functional connector of the brain (Sepulcre, 2014).

In this functional connectome, external or memorised information can come both from interactions between adjacent areas (e.g., same lobe), and from distant projections that form distributed brain systems (between different lobes). It seems that the brain has developed a functional balance that optimises the efficiency of information processing in different kinds of specialised areas, as well as mechanisms to modulate coupling in support of dynamically changing processing demands (Sepulcre et al. 2010). Such statements would highlight that the globular structure of the human brain, together with a

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notable increase in the parietal and temporal association areas (Bruner et al. 2018) and prefrontal (Semendeferi et al. 2002), would be especially important for increased cognitive performance.

However, the functional organisation is more complex than this basic hierarchisation, because although it is real in its anatomical concepts (Luria, 1966; Kandel et al. 1995; Sepulcre, 2014), in the development of the cognitive functions it follows a different structure not yet well known, although in its location it seems to be more or less homogeneous among human beings. Thus, it is frequent that some of these functional areas are shared in the performance of other cognitive functions, where small networks are functionally located within larger networks, and these in even larger networks (Sporns, 2011). This structure of multiple overlapping networks would explain that in the development of cognitive abilities, neurological networks, common cognitive functions, or general domain processes are shared (Kunze et al. 2019).

In the localisation of cognitive properties in the brain hemispheres, it seems that there must be a certain innate gradient defined as the existence of a differentiated maturation process in both hemispheres that acts in favour of one or the other, depending on the sensory modality involved (Bub & Whitaker, 1980; Geschwind & Galaburda, 1984; Kandel et al. 1995). Its definitive development correlates with a multifactorial model for the ontogenesis of hemispheric asymmetries, which includes multiple genetic and epigenetic factors (Brandler et al. 2013). In this context, it must be assumed that the origin of cognitive abilities must be adjusted to the characteristics of these synaptic structures. Therefore, each cognitive capacity would be the result of the coordinated action of various neuronal networks (some common with other capacities) located in specific areas of the cortex but consistent with the above-mentioned hierarchy.

As a conclusion, we can state that we inherit a nervous system specially prepared to process the information that reaches it through the senses (culture), and to form functional neurological structures as the basis of the cognitive capacities. The lack or inadequate source of information (social or sensory isolation) would produce a very deficient psychobiological development in terms of behaviour (Eccles, 1989).

3. The environmental influence on human societies

In general, all living beings develop their evolutionary mechanisms in continuous processes of adaptation to the changing environment in which they live. The same thing happens with human populations, but we must think that their environmental characteristics change radically with the development of their culture. Indeed, the creation of a cumulative culture of great cognitive completeness in its creation, transmission and maintenance, means that their environment presents special characteristics, forming what are currently called human niches (e.g., Tomasello 1999; Bickerton 2009; Pinker, 2010; Rivera & Menéndez, 2011). These would have a clearly different evolutionary importance to that which the ecological environment could exert on its own.

The adaptive improvements that were achieved at the beginning of our evolution (specifically human natural selection: niches) favoured the genetic changes that modulated the anatomy that was best adapted to the production of these cultural forms (Lotem et al. 2017), constituting what has been called the Baldwin effect (Bateson, 2004). Thus, a niche would be built (Odling-Smee et al. 2003) with cognitive-cultural characteristics capable of directing neuroevolution in the path of our specific cognitive development (Rivera & Rivera, 2019). Although there are certain limitations, it is possible to follow the cultural and social development of the genus Homo through Archaeology and Social Anthropology.

In conclusion, the brain has been selected for its capacity to store and manage information, acquired through social learning (Muthukrishna et al. 2018). Its evolution, within the human niches created by the genus Homo, has provided neurological structures with a functional disposition for the development of certain cognitive capacities, but which are not capable of being generated by themselves, requiring a cultural influence that structures them to make them functional within what we consider to be cognitive capacity. Culture would be the main driving force in human cognitive evolution (Bender, 2019), as the new natural selection of human niches will direct evolutionary and cognitive changes, definitively shaping the cognition of human societies.

4. Psychobiology of human cognitive evolution

The theoretical development of Psychology has been possible thanks to a series of conceptualizations about the cognitive characteristics observed in human behaviour. Such concepts have been called constructs or concepts that cannot be observed (Bunge, 1973). The constructs do not have immediate empirical references. No one has seen or touched someone's intelligence, but they can infer it from the way a person is able to solve certain problems in relation to the way others do them. These are theoretical concepts that go beyond empirical observation. In this context, the cognitive abilities observed in

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human behaviour can be integrated into the concept of constructs, which means that we can know their behavioural manifestations, but not their genesis and relationship to each other.

The interrelationship between the aforementioned psychoneurological foundations leads us to believe that there is an enormously organised neurological and psychological structure, in which there should be practically no cognitive elements (constructs) with totally isolated and individual functions and actions in their task. Its study has always had an important anthropocentrism, so that the relationship of human cognitive capacities with the rest of living beings has been practically limited to marking the great difference that can be observed between them. Likewise, until a few years ago it was considered that human ontogenesis would be very marked by a genetic base, without substantially valuing the importance of specifically human environmental influence (cultural niches). Undoubtedly, it is necessary to overcome this anthropocentrism and admit that there are numerous cultural antecedents in different biological species, so that diverse behaviours are clearly learned in their respective social groups (e.g., Whiten et al. 2005; Ottoni and Iza, 2008; Barrett et al. 2012; Heyes, 2012; Whiten & Erdal, 2012; Creanza et al. 2016), which were acquired through the neuronal bases of learning in the cultural transfer within their societies (Creanza et al. 2016). The existence of these antecedents in the animal kingdom (i.e., the basic ones to start the creation and use of tools) provide us with important information about the possible origins of the first phases of human niches (Whiten, 2011; Creanza et al. 2017).

Everything indicates that many of the human cognitive capacities are inherited in the form of potentiality (non-specific neurological base), which is developed through the appropriate influence of the environment (cultural and cognitive niches). Thanks to our neuronal plasticity we are highly dependent on environmental influence (human niches), so much so that even innate cognitive abilities (rational and emotional) can be functionally modulated throughout our ontogenesis. Likewise, the development of other cognitive capacities is achieved through the functional evolution of innate capacities, the greater neurological capacity of our brain (greater functional surface area, synaptic capacity and transmission speed) and the constant and essential influence of human niches (cultural and cognitive). To achieve this, we know several psychobiological mechanisms that always act in coordination within our ontogenesis: exaptation, co-evolution, and cognitive emergence.

4.1. Evolutionary exaptation

In evolutionary biology, various morphological structures were analysed to which a certain function is attributed in the present, but which, according to the data from the fossil records in their early period of evolution, had a different purpose from the one intended at present. In 1982, Gould and Vrba introduced the term exaptation for the characteristics that improve physical ability in their current function, but that did not evolve for that function by natural selection (Wilkins & Dumford, 1990; Gould, 1991; Skoyles, 1999).

This concept was extended to the cognitive abilities that may appear after the evolution of the necessary neurological changes, which did not evolve for that purpose (Gould & Lewontin, 1984; Schlaug et al. 1994). When analysing behaviour in prehistory we see that neuroevolution does not seem to be aimed at the creation of the high cognitive capacities that shape our behaviour (language, theory of mind, self-consciousness, writing, symbolism of all kinds, etc.), but at the collection and processing of the information that can be acquired from the observation of the environment, which puts us on the path of the evolutionary concepts of exaptation (Gould & Lewontin, 1984; Schlaug et al. 1994). These functional changes can only occur thanks to the non-specialised characteristics of the brain, but with a great potential for adaptability, such as the great neuronal plasticity and its dependence on the environment to complete its functional structure.

However, this evolutionary characteristic was defined at the end of the last century, being a general concept deduced from the evolution and paleontological knowledge, with little references to the causes that produced it. Therefore, more than being a mechanism of cognitive evolution it would be a morphological appreciation of a changing purpose in time that can be used in cognitive evolution. This leads us to consider that the main mechanisms of cognitive evolution would be co-evolution and cognitive emergence.

4.2. Cognitive co-evolution

Intraspecific co-evolution refers to the reciprocal changes that occur in organisms belonging to the same species, in this case referring to the cognitive processes characteristic of the genus Homo.

We have already seen how human cognitive abilities have important antecedents in the biological species that preceded us in evolution (e.g., Whiten et al. 2005; Ottoni and Iza, 2008; Barrett et al. 2012; Heyes, 2012; Whiten & Erdal, 2012; Creanza et al. 2016), which indicates that cognitive evolution has been much more gradual and incremental than previously assumed (Heyes, 2012). The creation of human niches will have a fundamental influence on genetic evolution and on the observable

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phenotype, by creating a specific natural selection that can favour genetic changes that improve the neurological base of cognitive abilities (e.g., Laland et al. 2000; Bufill and Carbonell, 2004; Creanza et al. 2017; Laland, 2017; Bender, 2019), being the origin of many of our cognitive processes. Authors such as Tomasello (1999) indicate the existence of an important relationship between culture and human cognition by creating dynamic models about its origin and development, which can be defined as a co-evolution between the culture of populations and their genetic heritage (Durham, 1991). Such co-evolution implies certain changes in the neuronal networks used, although always within the physiological possibilities of variation that these allow. These processes have had various explanations such as the cultural recycling of cortical maps (Dehaene 2005; Dehene & Cohen, 2007), neuronal reuse through culture (Colagè & d'Errico, 2018), or accelerated cycles of evolutionary feedback (Laland, 2017). In short, the effect of culture on cognitive evolution is achieved through small co-evolutionary modifications between learning and data acquisition mechanisms, whose coordinated action is critical for building effective neural networks (Lotem et al. 2017). All these works conclude with the concept that culture would be the main driving force in human cognitive evolution (Bender, 2019).

4.2.1. Basic factors of human cognitive evolution

It should be noted that the brain is a complex organ, where various evolved structures of different functionality have been overlapping and converging and are continuously being reshaped by culture. Therefore, the following interdisciplinary factors must always be considered when trying to analyse human cognitive development:

- The neuroevolution of the human lineage would be an evolutionary continuation of our biological ancestors. From them we acquire certain innate abilities (perception, attention, memory, recall, emotions and possibly, a minimum manifestation of executive functions depending on the neurological development of each species). We also see how the first forms of cultural influence on cognitive development appear, achieving some degree of development in the capacities considered until recently to be exclusive to human beings (theory of mind, causal cognition and certain development of the executive functions necessary for the use of natural elements like tools, including the first introduction of the protolanguages). These would be the result of the creation of a precultural environment that develops in clear social environments and is transmitted through basic learning mechanisms: imitation, emulation, etc. (e.g., Barrett et al. 2012; Heyes, 2012; Whiten & Erdal, 2012; Creanza et al. 2016).
- Neurological evolution provides a greater capacity to store and process information acquired through social learning (Muthukrishna et al. 2018). This would be the consequence of the significant increase in the synaptic production capacity and the improvement in the transmission of information between different cortical areas. The result would be an increase in the capacity of selective processing or synaptic computing (depending on the quality and quantity of the incoming sensory information), always promoted by the action of innate cognitive abilities and the level of development of those promoted by cultural influence.
- Brain functionality would be based on hierarchically functional neurological structures, which will organise the use of incoming and/or stored information. In general terms, the primary areas would be the first organisation of each modal stimulus; the secondary areas for multimodal reunification referring to the same object, biological entity, action, etc. and the tertiary association areas to generate adequate response processes. The evolution improves the anatomical and functional predisposition for the development of certain capacities (potentiality), but does not produce automatic mechanisms of elaborated responses, except for those already indicated as innate. There will always be a need for external information for their creation.
- The development of culture (cumulative culture) constitutes a new natural selection of specific characteristics within human niches, which surpass the general adaptive capacity produced simply by ecological pressures.

4.2.2. Influence of culture

Cultural influence can act on genetic, neurological, cognitive, and cultural factors, which is of enormous importance for our cognitive development (Bender, 2019).

- Influence on population genetics. This would be the functional and/or adaptive improvement of an innate capacity through genetic changes promoted by cultural influence, which is referred to as gene-cultural or biocultural co-evolution (Boyd & Richerson, 1988; Durham, 1991). The best-known example would be lactose tolerance, because by increasing the consumption of milk as a cultural form from the Neolithic, the part of the population that tolerated milk could increase its demography, to the detriment of the population with the genes that presented intolerance (Laland et al. 2010). This is included in the Baldwin effect (Bateson, 2004).

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- Action on neurological structures. A cultural innovation can trigger changes in the neurological structures of individuals due to neuroplasticity, as the brain's response to intensive and long-lasting experiences from various cultural practices (targeted learning and teaching). If its impact is so profound as to reconnect the brain, we talk about cultural recycling of cortical maps (Dehaene 2005; Dehaene & Cohen, 2007), neuronal cultural reuse (d'Errico & Colagè, 2018) or ontogenetic recruitment and reorganisation of pre-existing neuronal structures (Jablonka et al. 2012). The prototypical example of this is the formation of a new brain network by learning to read and write (Dehaene et al. 2015), which can be carried out throughout human ontogeny.

However, if the cultural influence is from birth, rather than reconnecting, recycling or reusing the neurons in the cortex, what is produced is a new functional structuring as neurological support for the cognitive abilities created by the external influence. In addition, we are aware of other human capacities (e.g., language and self-awareness) that must be realised before the end of their particular critical period, since after this period they could not be realised or would not have the same development as they would have within this period (Grimshaw et al. 1998; Gómez-Robles et al. 2015).

- General cognitive abilities. A cultural innovation can also trigger changes in general cognitive abilities through cultural exaptation. This process uses existing cognitive-cultural traits for a new purpose, such as when the application of ochre for skin protection is adapted for other purposes of a symbolic nature (d'Errico & Colagè, 2018; Bender, 2019).

- Influence on cultural development itself. Cultural transmission is the key mechanism by which cultural innovations lead to changes in culture itself. Active teaching and process-oriented learning help to accumulate such innovations (cumulative culture), as do social interaction and communication in general, thus providing subsequent generations with an especially important adaptive advantage from the very moment such cultural novelties are acquired (Tennie et al. .2009; Heyes, 2012; Morin, 2016). Cultural evolution would lead to the construction of new niches with cultural forms that can transform cognitive skills (e.g., Menary, 2015) into any of the previous forms.

These forms of cultural interaction usually act together, which is the expression of the processes of cognitive-cultural co-evolution. Human culture can create cognitive artefacts (Hutchins, 1999), such as writing or numerical systems (Seitz, 2020), which will serve as new cognitive elements to create new forms of culture. This form of co-evolution encompasses many human cultural forms, both technological and social. Thus, within cultural cognitive niches (Rivera & Rivera, 2019) there are selective pressures for technical (e.g., tool making) and social (e.g., increased cooperation) skills, which may have fostered the evolution of a set of cognitive processes. Learning to make complex tools and using them within a social logistics requires the kind of inhibitory control that allows for organization, patience and social tolerance, as well as generating new forms of human emotion (Heyes, 2012; Sterelny, 2012). All these feedback processes between culture and human cognitive capacities indicate the importance of social and technological experience in the ultimate configuration of cognitive processes, within a deep cognitive-cultural co-evolution (Barrett et al. 2012; Sterelny, 2012; Rivera & Rivera, 2019).

4.3. Cognitive emergence

Emergence is a general principle that can be applied to the understanding of change and novelty in all the natural systems, and that in cognitive processes is conceptualised because of psychobiological self-organisation thus achieving a greater cognitive balance (Piaget, 1978; Lewis, 2000). The concept is consubstantial with both inorganic and biological nature since the union of several chemical elements results in another one with different physicochemical properties that could not be foreseen on the basis of the properties of the isolated elements. Thus, from the union of certain cognitive capacities other capacities with new properties appear (emerge) (Searle, 1997). However, the process cannot be explained simply as an addition of the properties of the first capacities, but by the fact that the whole is more than the sum of the parts (Searle, 1997; Mora, 2001).

Its development occurs during human ontogenesis, thanks to the cultural influence of the environment in which it develops (human niches). These influences would produce the co-evolution of the cognitive capacities necessary so that, after their functional union, they can produce the emergence of a new cognition (Overton, 2003; Valsiner, 2006). In general, most of the cognitive processes that are going to produce it involve learning, as they are primarily culturally based (Lotem et al. 2017).

Although this evolutionary mechanism would be closely related to co-evolution, it differs fundamentally in its achievements. While co-evolution achieves a greater functional development of the cognitive capacities used, emergence achieves the start of new cognitive capacities that are substantially different from the capacities from which they originated. Their production is achieved through a functional coordination of several abilities, which in turn may be co-evolving with each other and acquire better cognitive performance. The whole process would be included in a cognitive continuum until the production of new cognitive abilities of an emerging nature, different from the previous ones and with original properties. This emergence can

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only start to manifest itself when the co-evolution of the capacities that are going to produce it acquire an adequate development. Their production would be determined by cultural transmission and social interactions in a brain functionally predisposed to these developments (Bender & Belle 2017).

Self-awareness or reflective consciousness can be a clear example of such a process and, without a doubt, one of the least known aspects (both in its psychobiological facets and in its archaeological or historical appearance) and which has had more transcendence for our culture. Its genesis is due to the causal interactions between the cognitive components that can originate it (e.g., self-awareness, autobiographical memory, language, etc.), so that consciousness is causally emergent (Searle, 1997; Rivera & Rivera, 2017). However, in the study of our cognitive abilities it is difficult to separate it completely from the processes of co-evolution; first, because it is the result of the evolution of other cognitive abilities; second, its development into cognitive processes should not be conceptualised as an all-or-nothing process, since its manifestation can have several intermediate stages that are very difficult to understand.

5. General hypothesis of cognitive evolution

After knowing the genetic, neurological, environmental and psychobiological characteristics of our brain, it is possible to elaborate a general hypothesis about the cognitive evolution in the genus Homo.

We know of the existence of cognitive antecedents or an evolutionary continuum from our biological ancestors to our genus (e.g., Barrett et al. 2012; Heyes, 2012; Whiten & Erdal, 2012; Creanza et al. 2016). This fact contributes to the innate production of some rational and emotional capacities: perception, attention, memory, recall, innate emotions, and minimal development of executive functions (e.g., executing the escape, confrontation or playing dead, organising group hunting).

During the evolution of our lineage, important neuroevolutionary improvements occurred (increase in the cortex, greater synaptic capacity, increase in neurotransmission, etc.), which will configure a hierarchical structure of the functional connectome of the brain (Luria, 1966; Kandel et al. 1995; Sepulcre, 2014). This neurological structure has two fundamental aspects. The first is the ordered relationship of the synapse according to the origin of the information (primary or projection areas, secondary and tertiary association areas). The second would depend on the anatomical location of the neurons in the cortex. Functionally, three main regions can be established: the sensory brain (temporal, parietal and occipital lobes), the executive and emotional brain (prefrontal lobe and limbic system) and the motor brain (back of the frontal lobe). The temporal, parietal and occipital lobes receive, integrate and store (memorise) information that reaches the brain through the sensory receptors. This information must be passed on to the frontal lobe for its emotional correlation and the creation of a behavioural response through the activation of the premotor and motor areas. The increase in the cortical surface area of each of these areas of the cortex would mean an increase in the specific functional capacity of their neural networks, as they can have reception, integration, storage, processing, and execution functions.

The brain is an organ whose action is carried out by integrating the functions of each of its parts, but there are various nuances to this assertion (Rivera & Rivera, 2017). In the case of human consciousness Daniel Dennet (1991) indicates that there does not seem to be a centrality but rather a dissemination, since consciousness emerges from the interaction of various physical and cognitive processes in the brain. Edelman and Tononi (2002) speak of a dynamic centrality in the sense of the neuronal activity of multiple networks and maps interacting at the same time. Searle (1997) believes that consciousness is a macroscopic effect of multiple microscopic brain processes. For Llinás (2001) the centrality is not space but time, thanks to the temporal synchronisation of the activity of a multitude of neuronal structures in the cortex and thalamus by means of a sweeping wave that coordinates all of them, creating a unique representational system. Despite these theoretical discrepancies, everyone seems to agree that this cognitive capacity would be the result of the joint and coordinated action of various neurological areas at any given moment and in a continuous manner, hence constituting the path to follow in the research into our cognitive abilities.

Each of the known cognitive abilities would be the result of the functional interaction of various functional areas (co-evolution), which in turn, can support other specific behaviours or certain neurological activities. Cumulative culture offers from birth all the cultural information that is sufficient and necessary for cognitive development in accordance with current human characteristics (e.g., language). Therefore, any alteration of the cultural structure would have a direct impact on the cognitive development of the child who suffers from it (Eccles, 1989).

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6. Example of co-evolution and emergence

Once the general parameters that are going to produce our evolution and cognitive development have been exposed, it seems important to carry out a brief study on some representative cognitive capacity of the genus Homo, such as causal cognition.

Causality is the function that evidences the relation of cause and effect between material, social and cognitive processes. There is a relation of necessity between both processes (cause-effect), so that if the cause exists, there will be an effect, and vice versa; once the effect is known, there must be a cause (Stuart-Fox, 2015; Lombard & Gärdenfors, 2017; Bender et al. 2017, 2019; Rivera & Rivera, 2019; Bender, 2020). These inferences can be made in two directions, one from cause to effect with a predictive character, and the other from effect to cause with diagnostic aspects (Reips & Waldmann, 2008).

In the evolution of the causal reasoning, seven grades of ascending complexity have been established. In this classification it is necessary to include those cognitive capacities that either in an isolated way or in mutual co-evolution, are going to produce behaviours defined as cause or effect, with the aim of being able to establish a causal relationship between them or with another behaviour. Thus, the cognitive parameters of language, theory of mind, working memory and self-consciousness have been introduced, naturally in the different degrees of evolution within the continuum that is the evolution of cognitive abilities. The grades are as follows (Lombard & Gärdenfors, 2017) (Table 1):

Grade 1: Individual causal understanding. Simple relationship between a cause (e.g., a force) and its immediate resulting effect, which are directly perceived (e.g., blow and effect).

Grade 2: Cued dyadic-causal understanding. Two different agents taking turns to perform a similar action. The other's action causes an effect because it gives the same result as my action; mirror neurons are presumably involved in such inference (two children on a seesaw).

Grade 3: Conspecific mindreading. The causal intention of the actions of others is interpreted as being similar to my own, with the same effects (e.g., the direction of another's gaze may indicate his or her intentions, as we presume that he or she is acting as we would). The behavioural initiation of the basic and specific skills of the theory of mind (intuitive perception of what others think that responds to certain non-verbal codes that we have not consciously noticed) is appreciated (Tomasello, 1999; Gärdenfors, 2007; Stuart-Fox, 2015).

Grade 4: Detached dyadic-causal understanding. This grade depends on the ability to have two or more mental representations at the same time, but different. One direct sensory observation and the other a memory of similar experiences, in order to understand their cause-effect relationship between them. A conscious causal reasoning from the observed effect (clothes on a chair) to the unobserved cause (its owner, whom we can recognise, left it there) is established. An expansion of working memory is observed to keep more than two mental representations in mind.

Grade 5: Causal understanding and mindreading of non-conspecifics. The same as the previous one but with different species. Understanding of the cause-effect of the actions of other species, done in an indirect way (e.g., traces of their displacement) and with previous experiences. It also requires some development of mind reading and working memory.

Grade 6: Inanimate causal understanding. Attributing causes to inanimate objects (e.g., seeing an apple fall when it is windy). The cause has not been directly perceived but inferred. It requires a development of working memory, behavioural flexibility, language, and self-awareness.

Grade 7: Causal network understanding. This is the most complex of all. It would be the understanding of how a set of causal nodes specific to one domain connects or links to the causal networks of other different domains. It requires a development of the theory of mind (Tomasello et al. 2005; Gärdenfors, 2007), and an initiation of mental and temporal planning (Lombard & Gärdenfors, 2017), as well as working memory, language, and self-awareness. It provides the principles that allow human beings to create meaningful causal hypotheses, which facilitate learning and reasoning about new causal systems in an amazingly effective way (Tenenbaum & Niyogi, 2003).

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Table 1.
Shows the seven degrees of causal cognition with their characteristics, as well as the cognitive needs they require for their emergence.

DEGREES OF CAUSAL COGNITION		
GRADE. DEFINITION	**CONCEPT**	**COGNITIVE COEVOLUTION**
1 Individual causal understanding	Relationship between a cause and its immediate effect	Learning by conditioning Perception, attention, memory and recall Experience
2 Dyadic-causal understanding	Two different agents in turns in a joint action	Perception, attention, memory Experience
3 Cospecific reading of the mind of others	The causal intent of the actions of others is similar to mine.	Perception, attention, memory Experience Basic and specific skills of the theory of mind. Language
4 Separate dyadic-causal understanding	Having two or more mental representations at the same time, but different in their production (sensory and memory).	Perception, attention, memory Experience Some basic level of executive functions. Language Expansion of the working memory
5 Causal understanding and non-specific mentality	Understanding the cause-effect of the actions of other species,	Perception, attention, memory Language. Experience Theory of mind. Developmentofworkingmemory
6 Inanimate causal understanding	Attribute causes to inanimate objects	Perception, attention, memory Experience Working memory, behavioural flexibility, language,
7 Understandingthe causal network	Domain-specific causal nodes connect or link to causal networks in other different domains	Perception, attention, memory Experience Theory of Mind Working memory, behavioural flexibility, Language, self-awareness

Each grade would be the result of a cognitive emergence based on the co-evolution of the cognitive capacities that are necessary to produce the causal and consequential (effect) factors to be related. Thus, the emergence of behaviours related to the degree we are analysing would take place in certain evolutionary periods.

Conclusion

We can conclude that evolution has created the neurological bases necessary for cognitive development, but it is culture (the new parameter of natural selection) that will direct the evolutionary and cognitive changes, definitively shaping the cognition of human societies. Therefore, the origin and development of human cognitive abilities implies an evolutionary process that, starting from some cognitive abilities of innate nature, can be carried out through the selective pressure of culture within human niches. Such a process would form a continuum development of most cognitive capacities, within a complex mechanism of mutual interaction between them, through the mechanisms of exaptation, co-evolution and/or emergence.

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The result is diverse, as while some cognitive abilities needed, at least in part, a neuroanatomical evolution that would favour their development (e.g., working memory, language, abstraction, etc.), others, using the previous ones, emerged with the cultural influence on brains already preformed for their realisation (e.g., theory of mind, causal cognition, self-awareness, reading and writing, etc.). In this context, the use of constructs will continue to be useful in the understanding and study of our abilities, but they would be seen as the result of the functional union of other cognitive processes with diverse purposes and origin.

These conclusions, which can be framed within the Psychobiological and Social or Functional Structuralism model for the analysis of our behaviour in the past and present (Rivera & Rivera, 2019), offer us a phylogenetic and ontogenetic vision of the development of our cognitive capacities. Such a neuropsychological and evolutionary (psychobiological) conception can constitute a well-founded basis for the study of its origin, development and behavioural manifestation within the wide range of possibilities that we know thanks to archaeology and psychology. Therefore, we recommend its reading to all those interested in the study of human behaviour, whether in the past (Cognitive Archaeology) or in the present (Neuropsychology), Its reading, understanding and critique will favour its methodological development, achieving a better application to all evolutionary periods and conditions.

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