MECHANISMS OF COGNITIVE EVOLUTION OF GENUS *HOMO*

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ABSTRACT. The objective of this work is to analyze the biological, social and environmental mechanisms that made possible the cognitive evolution of our lineage. To this end, an interdisciplinary study is proposed along with the most influential sciences on human behavior (evolutionary biology, neurology, psychology, neurolinguistics, social anthropology, etc.). Our purpose is not to delve into any particular topic within these sciences, but to coordinate their most recent data to establish a psychobiological and social model (functional structuralism) on our neurological and cognitive evolution, which will allow us to analyze the transformations—according to the archaeological record—from the beginning of the genus *Homo* to the present day. The main propulsor of these changes would be causal cognition as a neurophysiological mechanism that produce the evolutionary development of human cognition (social, emotional and technological). This process, based on the exaptative character of our brain, presents a clear co-evolutionary procedure that makes possible the emergence of human cognitive capacities.

KEY WORDS. Cognitive evolution, interdisciplinary method, causal cognition.

1. INTRODUCTION

The behavioral evolution of the genus *Homo* has traditionally been explained as a consequence of brain evolution. However, archaeology itself has noted the existence of a significant time lag between neurological evolution and behavioral development. This is what several authors have called *sapient paradox* (Renfrew, 2008). Why did modern cultural forms take time to develop if the anatomical basis evolved earlier? In order to have well-founded answers it seems necessary to know the psychobiological characteristics of our lineage, since they must have an important relation-

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ship with cognitive and cultural evolution (Renfrew, et al., 2009; Rivera and Menéndez, 2011; Malafouris, et al., 2014).

In this paper, we will try to elaborate an interdisciplinary theory on the production mechanisms of human cognitive evolution. In order to carry it out, we would use the data that various experimental sciences offer us, trying not to contradict each other, nor with the reliable data of the archaeological record, that is to say, to carry out an adequate interdisciplinary coordination.

2. METHOD

Through an interdisciplinary use of sciences related to human behavior (evolutionary biology, neurology, psychology, neurolinguistics, social anthropology, etc.) a theoretical hypothesis on human cognitive development *(Psychobiological and Social Model)* will be made. Its foundation would be the basic and common way of knowing and processing the material reality of the world in which we live *(Functional Structuralism*) (Lévi-Strauss, 1964). Interdisciplinarity attempts a systematic search for theoretical integration from different disciplines, starting from a multidimensional conception of phenomena, as well as the recognition of the relative character of separate scientific approaches (Piaget, et al., 1973). Such an attempt will be made through a progressive development of the following sections: neurological evolution, functional structuring of the brain, environmental interaction, causal cognition, general conditions of cognitive development and psycholinguistics (table 1).

2.1. NEUROLOGICAL EVOLUTION

In the evolution of our brain, the action of the regulating genes or *Hox* (heterochronies) had special relevance. It has been proved how some of them act in the production of

folds or *gyrification* of the cerebral cortex increasing notably its functional surface (Rilling and Insel, 1999; Cela Conde, 2002). This is the case of genes such as ARHGAP11B (Florio, et al., 2015); the TRNP1 gene with its participation in the control of tangential and radial expansion of the cerebral cortex (Stahl, et al., 2013); of the SRGAP2 gene and its successive mutations relating to neocortical development and neuronal plasticity, favoring a greater number of connections between neurons (Dennis, et al., 2012); and the most recent gene (NOTCH2NL) related to the increasement of the cortex in diverse areas (Suzuki, et al., 2018). These genes mediate in the transcription factors that initiate and/or stop the developmental processes performed by other genes, such as the control of the time of creation of *proliferative units* in the embryological formation of the cortex (Allman, 1990; Finlay, et al., 2001; Rakic and Kornack, 2001).

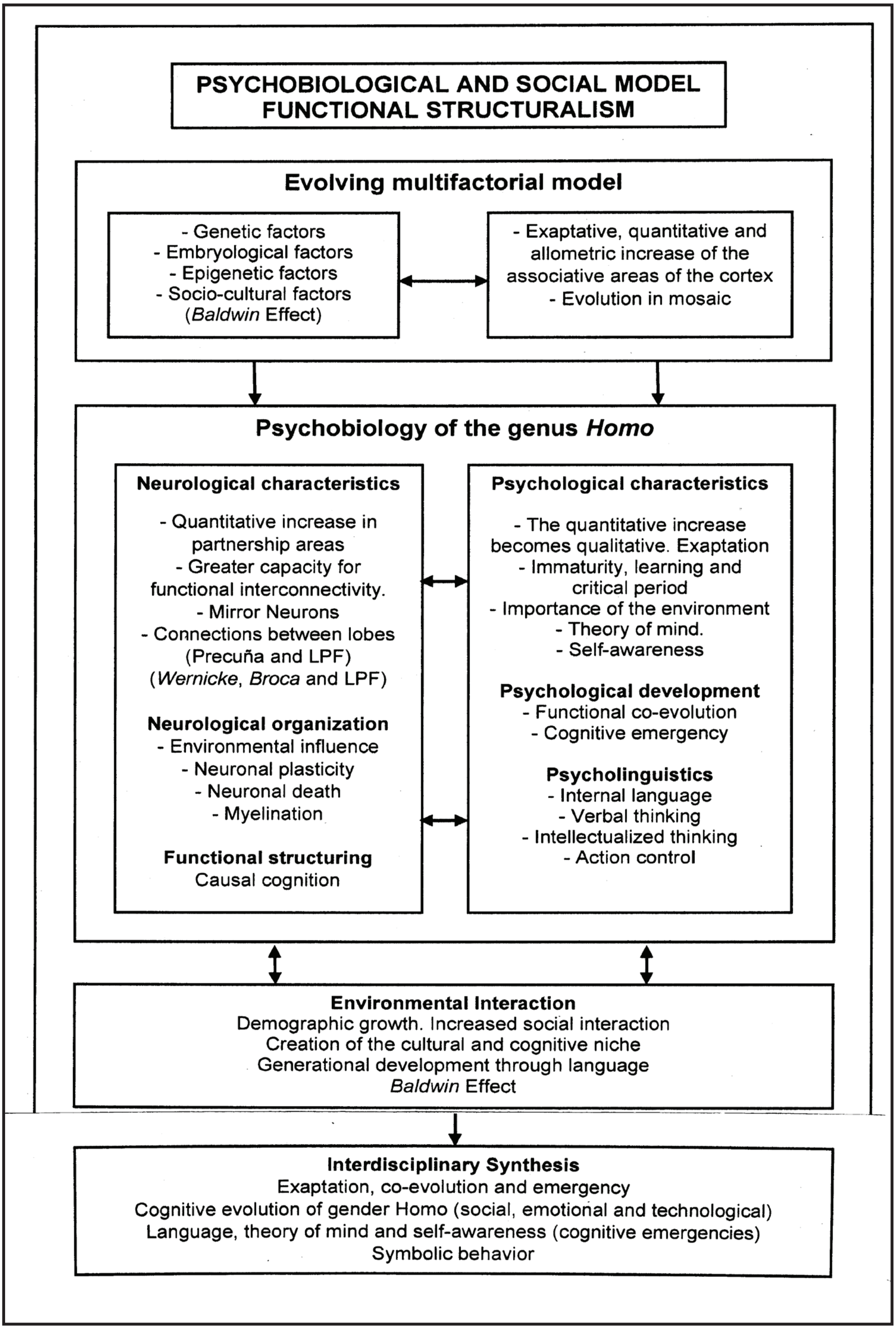

TABLE 1.
Interdisciplinar general scheme of human cognitive evolution.

These evolutionary actions explain the increasement of the functional cortical surface and a greater synapse capacity, showing an *allometric* and *quantitative* character (Florio, et al., 2015). A greater synaptic potential is acquired to allow the creation of neural networks of cognitive content, with an expanded capacity to process information. The concept of evolutionary *exaptation* (Gould, 1991; Skoyles, 1999) is relevant here, since certain cognitive capacities may appear after the evolution of the necessary neurological changes, but which did not evolve for this purpose. In particular, it seems that the neurological evolution focuses mainly on the increasement of the quantity and quality of processing of external and/or stored information.

2.2. FUNCTIONAL STRUCTURING OF THE BRAIN

In our neurological structuring, the primary areas (sensitive and motor) constitute an innate functional photomap, which would later be completed by external afferences, constituting the sensitive and motor *homunculi* (Penfield and Rasmussen, 1957; Rakic, 1995). At the same time, the secondary areas of association would receive information already elaborated in the primary ones, and those of tertiary association from the most elaborated information of the secondary ones (Luria, 1966; Kandel, et al., 1995; Sepulcre, 2014). This hierarchical structuring causes the formation of neural networks which allows an ascending order in complexity in their task to create different cognitive functions. In the genus *Homo* the areas that most evolved were the associative areas with an *allometric* character that will affect their functional capacity (behavior). However, although there are exceptions (e.g., *Brodmann* area 10) there is no generalized increase in neuronal density, which facilitates the existence of adequate *interconnectivity* between neurons, as well as extensive and late *myelination* (Rilling and Insel, 1999; Semendeferi, et al., 2002; Gómez-Robles, et al., 2015).

In this context, the *qualitative or functional* increase of the cortex would be very dependent on the afferences it receives from the environment. Thus, *neuronal plasticity* (Kandel, et al., 1995; Gómez-Robles, et al., 2015), *neuronal death* or pruning in the early stages of life (Petanjek, et al., 2011; Gómez-Robles, et al., 2015), extensive and late *myelination* (Miller, et al., 2012; Bercury and Macklin, 2015) and the existence of a *critical period* are neurological processes that indicate the brain's dependence on environmental afferences for an adequate cognitive development (Grimshaw, et al., 1998; Gómez-Robles, et al., 2015).

We know that sensory afferences play an important role in the definitive functionality of any cytoarchitectural area (Kandel, et al., 1995; Gómez-Robles, et al., 2015). Processing the information that reaches the brain is based on the organization of neural networks and circuits of high complexity and multifunctionality, which must provide the *substrate* for human cognition and behavior. The realization of such substrate will follow a hierarchical order dependent on the associative complexity of the cortical areas already mentioned (Luria, 1966; Sepulcre, 2014). This processing occurs within the interactions between adjacent areas (same lobe), and as distant projections that form distributed brain systems (different lobes). It appears that the brain has developed a *functional balance* that optimizes the efficiency of information processing in different classes of specialized areas, as well as mechanisms to modulate coupling in support of dynamically changing processing demands (Sepulcre, et al., 2010). Such claims would highlight that the *globulose structure* of the human brain, together with a notable expansion in the areas of parietal and temporal association (Semendeferi, et al., 2002; Bruner, et al., 2003) may be very important for an improved cognitive performance.

We can establish a basic functional structure, where the parieto-temporo-occipital association area would be the receptor and integrator of external sensory afferences (primary visual, sensory and auditory areas). This integrated information, which can be associated (symbolized) by appropriate sounds or signs, depending on the processes of attention, would have to pass to the frontal lobe for emotional correlation, rational processing and the production of a motor response if necessary. The nerve pathways that can perform this function are not well known, but we can highlight the exit of two important areas: the *Precúneo* or *Precuña* and its connections with the prefrontal lobe (Bruner, et al., 2014) and the Wernicke area and the important evolution of the *Arched Fascicle*, which reaches both the *Broca area* and the *prefrontal lobe* (Rilling, et al., 2008).

In this functional equilibrium between local and distant functions, the acquisition of cognitive functions could take place thanks to the convergence of two or more projections of different sensory modalities on one zone of the cortex (Geschwind, 1965; Gazzaniga, 1998). This can explain the development of *causal cognition*, where two or more stimuli of the same or different modality or origin (sensory or memoristic) that reach the areas of association *simultaneously* and *repeatedly*, would be able to establish synapses between them and create a new neurological network, with a different behavioral response.

Thus, as external sensory stimuli (social, technological and emotional) are diverse, a series of intertwined causal mechanisms would be produced giving rise to *co-evolution* processes that would develop from simple to more complex in all their facets (learning, data acquisition and behavioral development), managing to create *complex networks* as the basis of the cognitive capacities observed in the different hominids of the genus *Homo* (Haidle, 2014; Stuart-Fox, 2014; Lotem, et al., 2017). The structure of these neural networks operates in a kind of *hierarchical modularity*, 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 capacities, common neurological networks or cognitive functions are shared.

2.3. ENVIRONMENTAL INTERACTION (HUMAN NICHES AND BALDWIN EFFECT)

All species live and develop in a given environment (*ecological niche*), but only populations of the genus *Homo* have a special dynamic relationship with it, as they can change their characteristics through their particular interaction. The cause is a special form of social relationship among the members of their communities, as well as a greater capacity to capture, process, assimilate and transmit the information that nature offers us, which would improve the capacity for adaptation and change. Its realization occurs through social learning, the creation and development of human language, and the *emergence* of new cognitive skills such as the expansion of *working memory*, and the development of a *theory of mind* and *self-consciousness*. These cognitive capacities, acting in appropriate coordination, allow the construction of this niche to be a process of permanent accumulation and transformation, in which behaviors, tools and ideas are improved from generation to generation. These concepts reflect the importance of culture, creating the so-called *cultural niches* (Tomasello, 1999; Bickerton, 2009).

The *Psychobiological and Social Model* proposes the hypothesis of the *cognitive-cultural niche* (Rivera and Menéndez, 2011). The definitive functional structuring of our brain (innate component) is carried out by the afferences that arrive from the environment (human niche). At the beginning of our evolution there would be a mutual feedback mechanism similar to that proposed (Tomasello, 1999; Bickerton, 2009), but with differences in the forms of cognitive change production (*exaptation, co-evolution* and *cognitive emergence*). Culture exerts a selective pressure that molds the parameters of learning and data acquisition, which in turn configure the structure of the network of neurological representation producing the *Baldwin effect* (Bateson, 2004). Thus, the anatomy of the brain can be selected to better accommodate the physical requirements of learned processes and representations (Lotem, et al., 2017), that is, a niche of *cognitive-cultural* characteristics would be created. Culture would be the driving force of human cognition (Colagè and d'Erricoc, 2018).

Psychobiological development (causal cognition). Grades

Causal cognition is defined as the ability to establish and/or recognize a relationship (cause) between two or more cognitive processes of the same or different modality (sensory or stored in memory), producing a behavior or consequence (effect). It would be able to integrate collections of individual events within an organized representation of chains and networks of causal relationships (Haidle, 2014; Stuart-Fox, 2014; Lombard and Gärdenfors, 2017; Lotem, et al., 2017; Gärdenfors and Lombard, 2018). Its development takes place together with the interaction of other cognitive capacities (*co-evolution*), in order to produce new cognitive manifestations (*emergence*), where the influence of the environment is determinant (Rivera and Rivera, 2017). Its production has allowed to establish a model of seven degrees of ascending complexity, although heterogeneous in its production within time and space (Lombard and Gärdenfors, 2017; Gärdenfors and Lombard, 2018), which we have expanded by introducing the parameters of *working memory*, *theory of mind* and *self-consciousness* (table 2).

Grade 1: *Individual causal understanding*. Simple relation between a *cause* (push) and its immediate resultant *effect* (fall), which are directly perceived. It is done individually and can be explained through conditioning learning.

Grade 2: *Cued dyadic-causal understanding*. Two different agents in alternative shifts perform a similar action. Both know that the action of the other causes an effect similar to theirs, where mirror neurons are presumably involved in such an inference (two children on a seesaw). For the understanding of the following degrees of causal compression, this degree is a requirement, being able to be an antecedent of the theory of mind, when developing in a social environment.

Grade 3: *Conspecific mindreading*. The causal intention of the actions of others is interpreted as similar to mine, with the same effects (the direction of another's gaze can indicate his intentions, because we presume that he acts as we would). One appreciates the beginning of the basic, social and specific skills of the *theory of mind*.

Grade 4: *Detached dyadic-causal understanding*. This degree depends on the ability to have two or more mental representations at the same time but with different etiology; one direct sensorial observation and one memory of similar experiences in order to understand their cause-effect relationship. A conscious causal reasoning is established from the observed effect (clothing in a chair) to the unobserved cause (its owner, whom we can recognize, left it there). An expansion of the *working memory* is observed to maintain more than two unequal mental representations at the same time. The *theory of mind* is reaffirmed by thinking that the other acts as we would.

Grade 5: *Causal understanding and mindreading of non-conspecifics*. Same as above but with different species. Understanding of the cause-effect of the actions of other species, carried out indirectly (traces of their displacement) and with previous experiences. It also requires some development of the *working memory*.

Grade 6: *Inanimate causal understanding*. Attribute causes to inanimate objects (seeing an apple fall when there is wind). The cause is not directly perceived, but inferred. It requires the use of *working memory* and some development of *behavioral flexibility* (linked to language and self-awareness).

Grade 7: *Causal network understanding*. 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 allows for the modern human trait of *cognitive flexibility* and unlimited behavior, expressed in complex technological, symbolic, and scientific innovations. A full development of *working memory, theory of mind, language* and *self-consciousness* is required. It allows the creation of significant causal hypotheses that facilitate learning and reasoning about new causal systems in a very effective way (Tenenbaum and Niyogi, 2003).

The discussed antecedents of the first forms of causal cognition among non-human primates are limited to grades 1 and 2, to a lesser extent to grade 3 and very limited to grade 4, but with a minimal and controversial development of the *theory of mind* within a specifically social context (Wood, et al., 2007; Sánchez-Cubillo, et al., 2012; Seyfarth and Cheney, 2013).

The differences between grades 3 and 4 (conspecific) and grade 5 (non-specific) are gradual, depending largely on experience with other people (grades 3 and 4) and the behavior of other species (grade 5). Grades 4 and above facilitate the relationship between known facts (sensory experience and memory), being able to predict the interventions of other species (grades 3 and 4) and the behavior of other species (grade 5). Grades 4 and above facilitate the relationship between known facts (sensory experience and memory), being able to predict causal interventions and transfer them to other contexts (Haidle, 2014; Stuart-Fox, 2014; Lombard and Gärdenfors, 2017). In this last group appears an expansion of the *working memory*, a key to the behavioral development of our gender (Stuart-Fox, 2014). Likewise, the *theory of mind*, a certain evolution of *episodic memory* and a beginning of mental and temporal *planning* (Lombard and Gärdenfors, 2017), with the progressive development of language and self-awareness (Rivera and Rivera, 2017) were developed. Therefore, causal cognition is a central concept of human cognition, which is progressively coming to light as a potential explanatory framework for cognitive evolution (Lombard and Gärdenfors, 2017; Gärdenfors and Lombard, 2018).

DEGREES OF CAUSAL COGNITION				
DEGREES	**CONCEPT**	**EXAMPLE**	**CHARACTERISTICS**	**NEEDS**
1 Individual causal understanding	Relationship between a cause and its immediate effect	Push-fall	Individual Perception and attention	Learning by conditioning
2 Cued dyadic-causal understanding	Two different agents take turns in a joint action	Two agents in an alternating common action	Social Basic dyadic-causal understanding	Beginning of the theory of the mind?
3 Conspecificque mindreading	The causal intention of the actions of others are similar to mine	The direction of the gaze can indicate your intentions	Social. Your wishes, intentions and beliefs are similar to mine. Same effects	Basic beginning of *the theory of the mind*
4 Detached dyadic-causal understanding	Having two or more mental representations at the same time of different origin (sensorial and memory)	Conspecific. Clothes in a chair. Someone left her there, you can recognize her, and he left	Social. Sensory observation and memory of similar experiences, understanding their existing cause-effect relationship between them.	*Theory of mind* Expansion of *working memory*
5 Causal understanding and mindreading of non-conspecifics	Understanding the cause and effect of the actions of other species	Non-conspecific Understanding of cause and effect: traces of their displacement	The development of the conspecific grades 3-4 and 5 (non-co-specific), is gradual depending on the experience	Development of *working memory* Previous experience
6 Inanimate causal understanding	Attribute causes to inanimate objects	Drop an apple when there is wind Cause effect	Individual and social	*Work memory, behavioral flexibility, self-awareness*
7 Causal network understanding	Specific causal nodes of a domain connect to the causal networks of other different domains	Science	Individual and social	*Work memory, behavioral flexibility, language, self-awareness*

TABLE 2.
The seven degrees of causal cognition and its dependence on other cognitive abilities.

2.4. GENERAL CONDITIONS OF HUMAN COGNITIVE DEVELOPMENT

At birth, we have three key processes in human cognitive development: *neurological immaturity*, *learning*, and the *critical period* (Grimshaw, et al., 1998; Gómez-Robles, et al., 2015). The large duration of this immaturity facilitates the assimilation of numerous information without apparent effort. In this context, learning acquires great importance (Gómez-Roblesm, et al., 2015). A series of intertwined causal mechanisms are produced, giving rise to mechanisms of *co-evolution* in ascending complexity, succeeding in creating *complex networks* as the basis of the cognitive capacities observed in the different hominids of the genus *Homo* (Haidle, 2014; Stuart-Fox, 2014; Lotemm, et al., 2017). The characteristics of external or cultural influence (*cognitive-cultural niche*) on the inherited neurological hierarchy are fundamental (Colagè and d'Erricoc, 2018).

The diversity of information received and stored can be grouped into highly interconnected theoretical functional structures, in such a way that for the development of each of them the existence of the others is necessary (*cognitive co-evolution*). These are social, emotional and technological cognition (table 3).

— *Social cognitio*n. It is defined as the relationship that each of the components of society has with the other members, and all of them with each other. Its creation requires the most social environments possible (Segovia Cuéllar, 2017; Susswein and Racine, 2008). Its development is influenced by various cognitive processes, which would always act interconnected.

— *Theory of mind* or the ability to understand and predict other people's behavior, knowledge, intentions, emotions and beliefs, in order to use flexibly these representations to guide social behavior (Dennett, 1983; Tomasello, et al., 2005; Sánchez-Cubillo, et al., 2012; Seyfarth and Cheney, 2013).

— In social relations the *mirror neurons* take special interest, as they reinforce the understanding of the existence of others as similar to us (we imitate their behavior, what others do we are interested in), related to the concept of the *theory of mind* (Martin-Loeches, 2008; Gallese, et al., 2009).

— *Self-consciousness* can be defined as the mental state in which one has knowledge of one's own existence (one feels oneself) and of the existence of the physical and biological environment (Searle, 1997; Damasio, 2010; Edelman and Tononi, 2000). It is a recurrent *cognitive emergency* (Gelman, 1995) and recurrent (Humphrey, 1999) produced by the functional unity of four processes that interact in time (evolutionary, ontogenetic and historical): *evolutionary increasement* of the human brain, central or self-consciousness, *autobiographical consciousness* and the development of *language* as a cohesive element (Rivera and Rivera, 2017). With *self-consciousness* a representation of oneself is achieved, and with the *theory of mind* is added that of others (Sánchez-Cubillo, et al., 2012), making clear the great functional interrelationship between both. It is fundamental for the development of grades 6 and 7 of causal cognition.

— *Executive functions* or the set of cognitive skills of superior organization and integration that allow the maximization of behavioral efficiency at a given moment (*planning, flexibility, working or operative memory, monitoring and inhibition*), that is, to transform thought into action (as language) and make effective its control (*self-consciousness*) (Fuster, 2002; Kane and Engle, 2002; Ardila and Ostrosky-Solís, 2008). They have been located in the tertiary association areas of the prefrontal lobe. There are indications that *metacognitive executive functions* depend significantly on culture and cultural instruments, as it has been proven that they are significantly correlated with educational level (Gómez-Pérez and Ostrosky-Solís, 2006; Ardila and Ostrosky-Solís, 2008).

— A special mention is to *working memory*, considered an important cause of our cognitive evolution and the beginning of modern behavior (Wynn and Coolidge, 2011). It allows keeping activated a limited amount of information, which is necessary for the good development of action at any given moment. This informative maintenance facilitates the functionality of orientation, attention, inhibition and monitoring of behavior in reference to motivational and emotional states of the organism (Tirapu-Ustárroz and Muñoz-Céspedes, 2005). Working with *constructs* gives rise to various explanatory theories about working memory. We will highlight Baddeley's and Hitch's model on working memory (Baddeley, 2000), or Goldman-Rakic's model (1998) based on the implications of the functional architecture of the prefrontal cortex, explaining how independent and simple systems can work together to give rise to complex behavior (Tirapu-Ustárroz and Muñoz-Céspedes, 2005).

— *Emotional cognitio*n. All behaviors have associated emotional factors that will favor or hinder their development (Fuster, 2002; Happaney, et al., 2004; Ardila and Ostrosky-Solís, 2008; Damasio, 2010). Emotions, with their basic innate production and subsequent cognitive-behavioral development (self-conscious secondary emotions), facilitated the evolution of social behavior and cognitive development (Turner, 2000; Rivera, 2015).

— Social cognition and *empathy* are the germ of *altruistic* behavior (Batson, et al., 2015), a consequence of the action of innate emotions remodeled (causal cognition) by the development of the *theory of mind* and *self-consciousness*. In a common context, *empathy* acquires a special interest, because it indicates the capacity of emotional perception of what another individual can feel. It would be strongly related to the *theory of mind* (cognitive component); to feel what another subject is feeling in a similar or equal way to what I can feel in the same situation (emotional component) and to respond compassionately to the problems that afflict him (social behavior) (Moya-Albiol, et al., 2010; Batson, et al., 2015; Rivera, 2015) even if it supposes a danger for me (Preston and de Waals, 2002). *Empathy*, *altruism, need, motivation* and curiosity constitute the main drivers of social, moral and/or ethical organization (Fitzpatrick, 2017).

With altruism appears mutualism or social action in carrying out cooperative activities from which all can benefit, being the origin of normative judgments (rights and obligations), division of work and assignment of status (Tomasello, 2009).

— *Technological cognition*. This includes all behaviors related to the production and use of any type of utensil outside the body (tools, weapons, prostheses, etc.) (Haidle, 2014; Gärdenfors and Lombard, 2018). In these themes, the development and the *visuospatial coordination* would have special importance (Bruner and Lozano, 2014). Since this behavior has left the most remnants in behavioral evolution, it has been the form of cognition that has been studied the most, but it should not be isolated from the development of the other two.

2.5. PSYCHOLINGUISTICS

At present, it is impossible to speak of a modern cognitive development (self-consciousness, symbolism, etc.) dissociated from language development, just as it is impossible to dissociate language from environmental influence (Vygotsky, 1934/1978; Bruner, 1984; Damasio, 2010). Language is the means by which we learn all the abstract concepts that human societies have been able to create throughout its history, and it also organizes the nervous system according to the qualities that such abstractions offer (Vygotsky, 1934/1978; Luria and Yudovich, 1972; Belinchón, et al., 1992).

Language merges with thought through a process of interiorization, giving rise to *verbalized thought* (thought regulated by grammatical rules and the lexicon learned: *internal language*), and on the other hand to *intellectualized language* (sonorous exteriorization of thought), being these processes those that give the child the particular characteristics of human behavior (Vygotsky, 1934/1978; Luria and Yudovich, 1972; Bruner, 1984; Belinchón, et al., 1992). This internal language would be responsible for several higher cognitive functions, since it transforms the perception of the subject, his memory, allowing the planning and regulation of action, making possible voluntary activity. Within these conditions, thought is allowed to control and regulate its own cognitive processes, and so our actions, consecutive to our thought, will be better guided and structured (Vygotsky, 1934/1978; Mercier, 2000).

The language we use is part of cultural heritage, so it is meant to be heard. To speak is to have reached a certain degree of neurological maturation and social integration capable of allowing such praxis and its abstract communication. What is biologically inherited is a set of anatomical and physiological proprieties (areas of *Broca* and *Wernicke*, *Arched Fascicle*, etc.) that facilitate the acquisition and the use of language (Rivera and Rivera, 2009), which in its turn definitively modulates this neurological base.

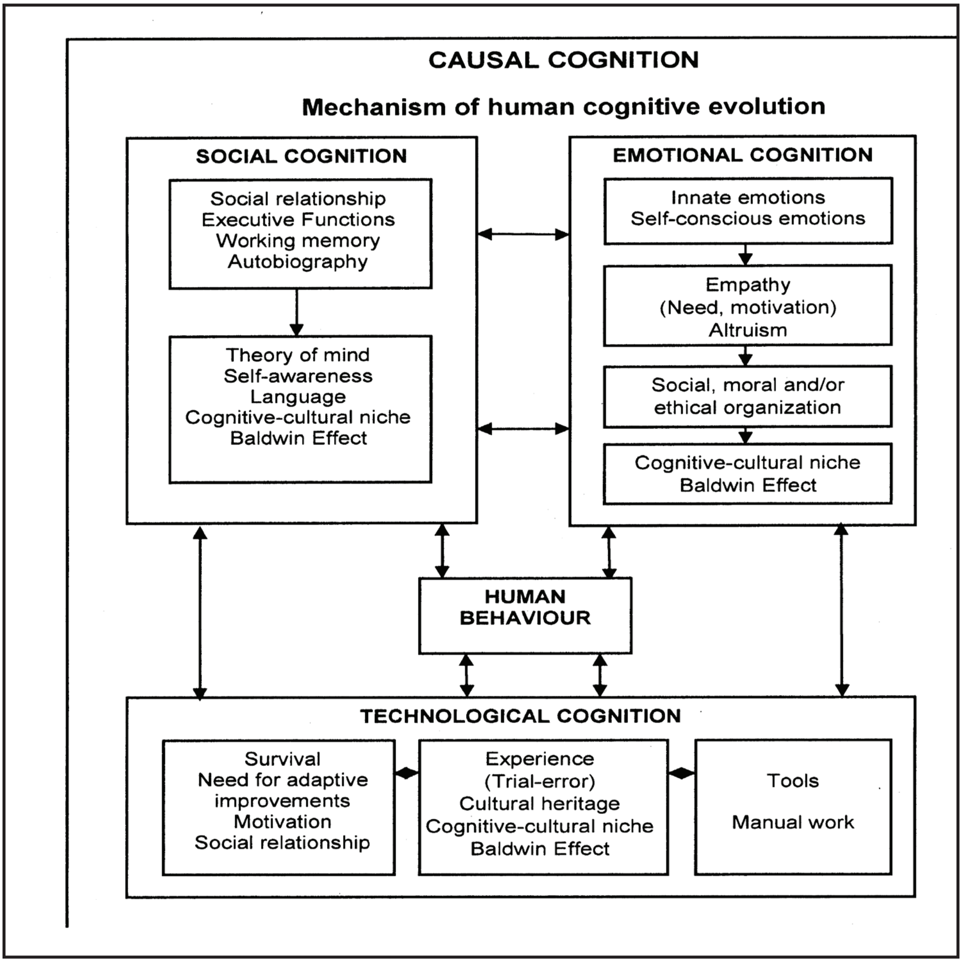

TABLE 3.
It reflects the different forms of cognition (social, emotional and technological), the relationship between them and their dependence on causal cognition as the engine of their creation.

3. PSYCHOBIOLOGICAL AND SOCIAL MODEL OR FUNCTIONAL STRUCTURALISM

The interdisciplinary union of all the above data and conclusions makes it possible to establish general laws on how hominids of the genus *Homo* were able to create and develop their behavior (tables 1 and 4).

— Biological evolution has endowed the genus *Homo* with *basic and innate functional capacities* both rational (attention, perception, memory, recall, causal cognition grades 1-3/4, and some level of working memory) and emotional (fear, anger, sadness and joy/happiness, disgust and surprise). Any rational action (individual or social) always includes an action of emotional cognition (Ardila and Ostrosky-Solís, 2008; Rivera, 2015).

— When neurological evolution is sufficient and environmental characteristics acquire an adequate level, new capacities of a socio-cultural nature can be produced, which only existed as *potentiality*. These are the *emerging cognitive capacities* (symbolism, language, self-consciousness, writing, etc.) (Vygotsky, 1934/1962; Searle, 1997; Tomasello, 1999; Edelman and Tononi, 2000; Mora, 2001; Álvarez Munárriz, 2005; Ardila and Ostrosky-Solís, 2008; Renfrew, 2008).

— The psychobiological characteristics of our lineage need an adequate environment for the basic cognitive abilities (rational and emotional) to develop adequately, as is the case with causal cognition 3/4-7. It could be defined as a *cultural-cognitive niche* that promotes such development, its influence being determinant.

— The existence of a language (first symbolic behavior) is a necessary condition for the formation, development and transmission of all developed behaviors.

— This cognitive development would be structured, depending on the diversity of the received or memorized stimuli, in three theoretical cognitive functions: social cognition (*theory of mind, self-consciousness*); emotional cognition and technological cognition. All of them are widely interconnected in their functionality. Its basic mechanism of production and development would be *causal cognition* in progressive complexity (Haidle, 2014; Stuart-Fox, 2014; Lombard and Gärdenfors, 2017; Waldmann, 2017).

— *Self-consciousness* is conceived as the *cognitive emergence* produced by the functional union of several cognitive processes that interact in time (evolutionary, ontogenetic and historical). Its development would enhance the functionality of other cognitions: social cognition (conscious level of the *theory of mind*), emotional cognition (development of *self-conscious emotions*) and technological cognition (development of social behaviors, symbolic, technological, cultural, and so forth).

— Its development would produce a *cumulative* process, constituting the *cultural heritage* of each population. In order to achieve this, a certain demographic stability is needed that facilitates its permanence, generational transmission and progress.

— The concepts and abstractions that are going to configure human behavior at all levels must be acquired from the environment in which one lives (observation, imitation, language, teaching), both one's own nature and of socio-cultural constructions that human groups establish.

— Cognitive and cultural evolution is a heterogeneous *continuum* in time and space, since it depends on diverse factors (cognitive capacities and development, existence of a previous language, socio-cultural environment, demographic conditions, emotiveness, etc.) that do not always act with the same intensity, nor do they have the same temporal and spatial development. What at the beginning is common (common psychobiological basis), in its development will diversified, which explains the *mosaic* aspect (cultural, cognitive and emotional) that characterize such processes.

— Along this *continuum* several *intermediate stages* are produced, of which we do not know their precise characteristics, but which we can hypothetically propose and contrast with the known data of the archaeological record.

— *Exaptation, co-evolution and emergency* are the mechanisms that will configure the characteristics of human cognitive evolution (Rivera and Menéndez, 2011; Rivera and Rivera, 2017).

<table>
<tr><th colspan="3">PSYCHOBIOLOGICAL AND SOCIAL MODEL FUNCTIONAL STRUCTURALISM</th></tr>
<tr><td rowspan="6">Interdisciplinary concept of cultural and symbolic evolution</td><td colspan="2">Basic cognitive abilities (rational and emotional)
(biological evolution)
Causal cognition. Grades 1-3 / 4</td></tr>
<tr><td colspan="2">Cognitive development. Emerging cognitive abilities
(cultural evolution)
Causal cognition 3 / 4-7</td></tr>
<tr><td rowspan="2">Terms necessary environmental</td><td>Social, cultural, economic, demographic and technological. Cognitive-cultural niche</td></tr>
<tr><td>Existence of a language. Language is the first symbolic and medium behavior for all cognitive development</td></tr>
<tr><td colspan="2">Causal cognition as a method of cognitive structuring (social, emotional and technological)</td></tr>
<tr><td colspan="2">Self-awareness is fundamental for the development of symbolic and modern behavior</td></tr>
<tr><td rowspan="4">Characteristics of cognitive evolution</td><td colspan="2">Cumulative. Cultural heritage. Accurate demographic stability</td></tr>
<tr><td colspan="2">The concepts and abstractions that are going to shape the behavior have to be acquired from the observation of the environment and the cultural heritage</td></tr>
<tr><td colspan="2">Evolution as a heterogeneous continuum in time and space.
Cognitive-cultural mosaic</td></tr>
<tr><td colspan="2">Multiple intermediate stages of cognitive evolution</td></tr>
<tr><td rowspan="3">General mechanisms of cognitive evolution</td><td colspan="2">Exaptation: cognitive functions for which it did not evolve</td></tr>
<tr><td colspan="2">Co-evolution: reciprocal cognitive modification</td></tr>
<tr><td colspan="2">Emergency: new capacity acquired by the functional sum of the elements of the system (co-evolution)</td></tr>
</table>

TABLE 4.
Diagram of the psychobiological and social model on human cognitive evolution.

4. CONCLUSIONS

This interdisciplinary study has allowed us to create a widely documented working hypothesis, hoping that it will serve as a working tool to understand the cognitive and behavioral evolution of the genus *Homo*. For its realization, we have valued the recent data on neurological evolution, which indicate that such evolution occurred mainly with the increasement of the processing capacity of the information of the associative areas (*allometric and quantitative*). However, this functional increasement required external information for its correct functioning and definitive structuring, since it is well contrasted that its absence or severe deficit (social or sensory isolation) would produce a very deficient final development.

External information always comes from the environment in which organism are born and developed; in the case of the genus *Homo* a specific *ecological niche* was created according to its properties (*cognitive-behavioral*). It would be constituted by all kind of cultural achievements that the diverse human populations create and add generationally to their *cultural heritage* (Colagè and d'Errico, 2018). The possible neurological mutations that favored or promoted the assimilation and development of the cultural characteristics of each Paleolithic period would be favored by the natural selection characteristic of the cognitive-behavioral niche (*Baldwin effect*). In this context, language must have had a main role, as organizer of cultural assimilation, social communication and functional structuring of the brain (internal speech). From the first components of our lineage we can appreciate the development of neurological structures strongly related to language (areas of *Broca* and *Wernicke*, *Arched Fascicle* and parietal development with its connections to the prefrontal lobe, etc.), that shows an important transformation and development between these structures in primates and current humans. Renfrew's *Sapient paradox* (2008) can already be answered: anatomical and cultural evolutions are not parallel. The first is fundamental, because it establishes the physiological basis for culture to act, but which must be created, symbolized by language and transmitted, which would take time, especially in the first human populations.

In this complex process, causal cognition seems to be the main foundation for the development of these forms of cognition, using stimuli and memories related to social, emotional and technological interaction. This process must be understood as a continuum development of heterogeneous characteristics in time and space. This process is a clear example of *cognitive co-evolution*, produced due to the *exaptative* and *mosaic* character of our neurological evolution, which in a suitable environment is capable of producing the phenomena of *cognitive emergencies* with their consequent changes of the symbolic behavior that characterizes us.

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