# LINGUAGEM, APRENDIZAGEM E DESENVOLVIMENTO: PERSPECTIVAS SOBRE AQUISIÇÃO LINGUÍSTICA E FUNCIONAMENTO CEREBRAL

## *LENGUAJE, APRENDIZAJE Y DESARROLLO: PERSPECTIVAS DE ADQUISICIÓN LINGÜÍSTICA Y FUNCIONAMIENTO CEREBRAL*

## *LANGUAGE, LEARNING, AND DEVELOPMENT: PERSPECTIVES ON LANGUAGE ACQUISITION AND BRAIN FUNCTION*

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**RESUMO**: O que nos faz humanos? A linguagem segue a frente nesta disputa que ainda não está plenamente resolvida pela ciência. O que se sabe até hoje é que somente humanos desenvolveram um aparato fonador apto a produzir sons em todas as línguas, em conjunto com uma circuitaria neural que possibilita que a comunicação passe a ser mais do que mero instrumento de transação, permitindo também a colaboração e a cocriação. Propõe-se nesta revisão sob a perspectiva do funcionamento cerebral o exame da relação entre linguagem, pensamento e aprendizagem; da hipótese de determinismo e relativismo linguístico para avaliar sua implicação para aprendizagem e desenvolvimento; de ideias atuais sobre a evolução da linguagem humana; das conexões entre desenvolvimento linguístico e herança genética para a capacidade linguística; da diferença entre a aquisição da primeira e da segunda língua; e como a correta identificação da dislexia e da afasia podem informar o entendimento atual do processo de aquisição linguística e seu desenvolvimento.

**PALAVRAS-CHAVE**: Linguagem. Circuitaria neural. Desenvolvimento. Genética. Pensamento.

***RESUMEN:*** *¿Lo que nos hace humanos? El lenguaje sigue adelante en esta disputa que todavía no está plenamente resuelta por la ciencia. Lo que se sabe hasta hoy es que solamente los humanos desarrollaron un aparato fonador apto a producir sonidos en todas las lenguas en conjunto con un circuito neuronal que posibilita que la comunicación pase, de herramienta de transición para permitir la colaboración y co-creación. Se propone en esta revisión , bajo perspectiva del funcionamiento cerebral , el examen de la relación entre lenguaje, pensamiento y aprendizaje; desde la hipótesis del determinismo y relativismo lingüístico para evaluar su implicación para el desarrollo y aprendizaje; de ideas actuales sobre la evolución del lenguaje humano; de los conectores entre el desarrollo lingüístico y herencia genética para esta capacidad; la diferencia entre la adquisición de la primera y segunda lengua; y como la correcta identificación de la dislexia y de la afasia pueden informar al entendimiento actual del proceso de adquisición lingüística y su desarrollo.*

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***PALABRAS CLAVE**: Lenguaje. Circuito neuronal. Desarrollo. Genética. Pensamiento.*

***ABSTRACT**: What makes us human? Language takes the lead in this dispute that has not been settled by science. What is known is that only humans have developed an apparatus fit for the production of sounds in all the known languages coupled with a brain circuitry that enables communication to become not only transactional, but also a matter of collaboration and cocreation. What is proposed in this review is to examine the relationship between language, thought, and learning; the hypothesis of linguistic determinism and relativism and its implication for learning and development; current ideas on the evolution of human language; connections between linguistic development and genetic inheritance of language capacity; the difference between first and second language acquisition; and how correct identification of dyslexia and aphasia can inform current understanding of the process of language acquisition and development.*

***KEYWORDS**: Language. Neural circuitry. Development. Genetics. Thought.*

## Introduction

This paper presents a brief overview of language acquisition from the viewpoint of contemporary brain research and cognitive psychology. Although many aspects of language processing and learning are not yet fully understood, especially with respect to functional brain development, this paper aims to provide a summary and update on the current state of this research, using examples of available data to illustrate a few of the prevailing theories. We aim to bring attention to several transdisciplinary threads which connect neuroscience, cognitive psychology, and linguistics with language studies and education, in general. We also hope this will provide a platform, upon which students interested in the study of language can gain a better understanding of language processing and its biological basis, in order to improve methodology for learning a second language or to design novel approaches for remediation of consequences associated with atypical development (e.g. dyslexia) or to later disability (e.g. aphasia).

## The relationship between language, thought and learning

For the purposes of this article, we understand language to be the accrual of shared meaning constructed within neurobiological systems that develop under the influence of a genetic program and social experience. This accrual comes from communication, conversation, collaboration and cocreation of meaning, and is the medium through which we perform higher order thinking activities. Views on what language is, range from those who believe that it is genetically determined and a consequence of biological evolution (CHOMSKY, 1980) to others who see it as a result of social interaction and communication (TOMASELLO, 2008).

Thought is the product of cognitive activities through which we hypothesize, conceptualize, structure and strategize in our inner and outer worlds. Learning is a developmental or maturational process mediated by experience and neuronal restructuring (KANDEL; SCHWARTZ, 1982). Learning results is the accumulation of knowledge and skills to better understand and make meaning of experience and thought (GARDNER *et al.*, 2000). We come to know our thoughts by conceptualizing them through language (SPELKE; KINZLER, 2006), and we come to know something, that is, to establish the relationships between what something (e.g. a word or concept) is as opposed to what that something means in face of new experiences through interactions mediated by language (BRUNER, 1990). In Bruner's view, use of language through narrative and its strong connection to culture is central to human cognition (MATTINGLY; LUTKEHAUS; THROOP, 2008; BRUNER, 1990).

Although these notions of learning generally apply to both children and adults, certain aspects of learning differ between them. Broadly speaking, a child's learning process is firmly based on the accumulation of and exposure to new information. This is essentially how children accommodate and assimilate experiences (PIAGET, 1995). For an adult, on the other hand, new information is just one of the resources he/she has with which to construe meaning. To be really imbued with any use, this new piece of information has to fit within a frame of reference, i.e., it has to be mapped onto prior knowledge – *schemata* - so that the resulting framework is used to guide future decisions (MEZIROW, 1997).

Also, it is worth noting that learning is a multi-faceted concept which is, as aptly stated by Vygotsky (1978, p. 83), "more than the acquisition of the ability to think". It stretches beyond the boundaries of accumulative processes to encompass language, thinking, perception, attention, memory and problem-solving (BRUNER, 2009). To go from one stage of development to another, a child, for instance, is dependent on inter- and intra-psychological processes mediated by language and enabled by guidance of an adult or collaboration with peers (BRUNER, 2009; VYGOTSKY, 1978).

Whether development and learning are viewed as dichotomous processes or as one and the same, language remains as an example of a highly cognitive skill that serves both constructs, is age-related and knowledge-related, and develops in an experience-dependent context. Language is inherently a skill honed by social interaction (BICKERTON, 2009), as exemplified by a child who, raised from birth in a multilingual environment, learns a second language (L2) in a way that is distinct from a child learning another language after the acquisition of the native language (L1) (BIALYSTOK, 2007).

And when faced with the dichotomy between language and thought – which comes first - it is important to remember that Vygotsky and Piaget diverged diametrically. To the former, language drives thought; it is by the egocentric, or inner, speech, that one comes to social speech. To the latter, thought drives language; it is by the mental representations that one constructs the language that gets developed (BRUNER, 1997). Therefore, when considering language development, which rules: language or thought?

## Linguistic determinism and relativism and their implication for language learning and development

When scholars tried to explain cognitive processes involved in language and thinking, several important theories evolved, among which is the Sapir-Whorf hypothesis. Whereas Edward Sapir, influenced by his mentor Franz Boas, proposed that humans are “at the mercy of the particular language which has become the medium of expression for their society” (SAPIR, 1929, p. 209); Whorf, his student, defended a societal agreement made possible through language (WHORF, 1940). They were contextualized and heavily influenced by the political landscape of the times in which they surfaced (GUMPERZ; LEVINSON, 1996), but are, nonetheless, important for understanding how we conceptualize the constructs that are at the core of this review.  If we understand language to be the cognitive element that allows us to live in society, introducing some of the theories that have shaped this conceptualization is useful here.

Benjamin Lee Whorf was the major proponent of linguistic determinism. In 1956, he developed a theory essentially grounded in Wittgenstein’s famous quote translated as “the limits of my language mean the limits of my world” (WITTGENSTEIN, 1980), meaning that our perception of experience is limited to the extent to which it can be shaped by the language we speak. It was radical and remains so. Even Wittgenstein (2009) went back on his own words. That is probably why it paved the way for a softer version, that of linguist relativity, in which one’s view of the world is influenced, but not limited, by the language one speaks. In either case, cognitive processes differ when different languages are used, and words are context bound (WOLFF; HOLMES, 2011). The ramifications of this are intriguing to consider when acquiring two languages simultaneously at an early age as compared to learning a second language (L2) after learning the first language (L1).

Using reaction times as a measure, recent studies focusing on the effects L1 thinking habits exert on L2 comprehension (BORODITSKY; GABY, 2010; FAUSEY *et al.*, 2010; DANZIGER; WARD, 2010) point to the idea that what constructs habitual thinking are constantly evoked linguistic maps (BORODITSKY, 2011), and that the age of acquisition for L2, as opposed to time of exposure for L2, is what influences thought (BORODITSKY, 2001). For abstract thinking, research carried under the framework of linguistic relativity (BORODITSKY, 2001) has demonstrated that L1 is fundamental in the modulation of one's habitual thinking. The same conclusion was reached for time related conceptualizations (CASASANTO; JASMIN, 2012), for spatial relations (PEDERSON *et al.*, 1998), for color perception (ÖZGEN, 2004), and for agency (FAUSEY *et al.*, 2010).

In summary, the fact that abstract conceptualizations (time, space, causality and relationships) take more time than concrete ones (sensory stimuli) to be formed means that acquiring them (the former) requires experience with language. Therefore, these conceptualizations will be shaped by the language one has been exposed to and practiced, leading us to conclude that the earlier one learns an L2, the more experience one will have with those abstract conceptualizations in the target language. That experience will in turn shape one's thought. Such experience calls to this review a consideration of how language is acquired and comes to shape so much of our thoughts and experiences[3].

## Overview of early language development

Humans brains come to this world partially wired for language. Although its complex form is only manifest in humans, it must be regarded a product of our evolutionary history (ARMSTRONG *et al.*, 1991; BICKERTON, 2009; LAUGHLIN; SEJNOWSKI, 2003; STAMENOV; GALLESE, 2002). Recent research, for example, supports the notion that our vocalization apparatus is uniquely structured for the production of language (GOKHMAN *et al.*, 2017). This research identified changes in gene regulation based on DNA methylation maps connected to skeletal development, facial projection and larynx development.

[3] Consideration must be given to opposing views. Lenneberg (1967) for instance, reputed language development as a genetically maturational process, as opposed to an environmental one. That side is partially taken by Chomsky (1980) whose groundbreaking hypothesis for the LAD (Language Acquisition Device) and UG (Universal Grammar) are firmly based on genetic predisposition. Such a stance is the one further defended by Pinker, who also embraces the idea of natural selection and genetic evolutionary disposition for language, sidelining with an evolutionary natural selection for language development, but still refuting the notion that language affects thinking processes (PINKER, 2003).

Humans are born with an ability to discriminate the sounds in all spoken languages, though the linguistic experience they have affects their phonemic perception as early as 6 months of age (KUHL *et al.*, 1992). In fact, before birth, we learn certain melodic features of our mother's L1. Some studies have even suggested that a baby's crying is shaped by the contours of this melodic prose (MAMPE *et al.*, 2009; WERMKE *et al.*, 2017).

The neurobiological systems for speaking and listening are in place when we come to this world (GARROD; PICKERING, 2004) and we acquire spoken language with relative ease. Reading and writing, however, require formal instruction and develop only with years of exposure and experience. Yet learning to read and write reconfigures our brain like no other previous experience does by co-opting neural systems that presumably evolved to serve other purposes (DEHAENE, 2009; DEHAENE *et al.*, 2010). In a coordinated process hypothesized as a neuronal recycling of our cortical maps, this reconfiguration establishes new patterns of neuronal activation and continuous development that shapes perception of all later experiences, thoughts, feelings, and their expression (DEHAENE, 2009; MCCANDLISS; COHEN; DEHAENE, 2003). As spoken language and the closely connected skills of reading and writing are acquired, fundamental relationships between language, learning, and thought are established such that each of these has the potential to influence the others in ways that are often unobservable to ourselves. What ensues is a new period of cognitive development.

## Achieving literacy and the interplay of nature and nurture

Once the human brain learns to decode the symbols that form our written world, neuronal circuitry and patterns of activity in neuroanatomical areas responsible for language processing are altered (DEHAENE *et al.*, 2010). This is analogous, in part, to the neuroplasticity manifested as functional reorganization in cortical maps after training on perceptual or motor learning (POLLEY; STERNBERG; MERZENICH, 2006; NUDO, 2003). The modifications in cortical maps correlate with improved performance on associated behavioral tasks. In the case of learning to read, on the other hand, areas recruited for reading served other purposes in our recent ancestors and in pre-literate humans. Once literacy skills are acquired, they assume the responsibility of processing for novel requirements (DEHAENE, 2010). Anyone who learns to read will never look at symbols that represent sounds (graphemes) without extracting or attempting to derive meaning from those stimuli.

Prior to achieving a state in which fluent reading is possible, at least sixteen neural networks have been identified that need to mature and act in coordination (PUGH *et al.*, 2013). Of those, twelve refer to cognitive processes: such as attentional networks, phonological awareness networks, concept formation networks and working memory networks. The remaining four networks belong to the social emotional realm and appear to support constructs such as self-efficacy, social cognition, teacher-student relationship and motivation (POLDRACK *et al.*, 1999; SIMOS *et al.*, 2001, TURKELTAUB *et al.*, 2003).

The existence of these multi-dimensional maturational processes leads us to understand that cognitive development does not take place through a fixed progression of age-related stages. Every individual has a distinct learning trajectory and develops individual skills differently based on network maturation occurring within a variable time frame according to the various experiences and stimuli in the environment he/she has encountered (FISCHER, 2008). This can mean that within a period of months we might observe the complete progression from one stage to a totally different one. On the other hand, a child can often appear not to move from one stage to another for much longer periods of time. We are not simply constrained to a fixed and predetermined timing of development according to biological age, but rather shaped by the complexity of our ontogenic development which is inconstant interaction with and responsive to the external world of our experience (TOKUHAMA-ESPINOSA, 2015; 2018; TOKUHAMA-ESPINOSA; RIVERA, 2013). We are the result of a constant and deeply rooted interdependent relation between our nature (i.e. biology and genes) and our nurture (learning experiences and environment). We are in part shaped by our genetic makeup and in part by our experiences in an interplay of no predetermined or fixed amount. Each of our individual learning trajectories is always subserved by our own unique genetic makeup. With that, we now turn to a brief look at how this inheritance may affect language development.

## Genetic basis for language development and biological connections

Early investigations of the genetic inheritance of language development include a study of a group of families that manifested common deficits in relation to language development (FISCHER; SCHARFF, 2009). They could not articulate sounds properly, had difficulty understanding language, and did not develop linguistically like the rest of their community. Upon further examination, through genetic mapping of their hereditary influences, researchers identified one factor that was present in all of the affected population: they had inherited a mutation in one specific gene, namely FOXP2, that was later (and probably prematurely) termed the ‘language gene’ (ENARD *et al.*, 2002). That mutation was associated with a form of dysarthria, that is, difficulty in articulating speech. It is worth noticing that other genetic variants exist, one of which, for example, is a grammar-specific deficit (VAN DER LELY; ROSEN; MCCLELLAND, 1998). These developmental disorders, referred to as Specific Language Impairments, can affect different aspects of language processing and are often associated with underlying structural abnormalities in neuroanatomy (VAN DER LELY; PINKER, 2014; FRIEDERICI, 2017).

In parallel with maturational processes controlled by genetic determinants, the nervous system develops in conjunction with information flowing to the system from the environment, in this case, language input. Chomsky (1986) has argued that the acquisition of language is strongly biologically determined in humans and that all languages used by humans are fundamentally structured around an innate universal grammar. Owing to the fact that the development of language ability after birth is rapid in most children as is the sequence of developmental phases, Friederici (2017) argues for a strong biologically influence on first language development. She has reported that German 4-month old infants can discern grammatical inconsistencies in a language other than German (i.e. Italian) after hearing only a few sentences of the incorrect form.

In an intriguing study that needs further support and remains inconclusive, Poeppel (2017) identified oscillations of specific frequencies in cortical regions that correlated with structural aspects of language (e.g. syllable, word, phrase) rather than simple acoustical properties of sounds perceived. The observations generalized across languages and sentence length. The oscillatory patterns that reflect syntactic structure as perceived by a subject might reflect the neural signature of the elusive predisposition for linguistic development that Chomsky (1980) has sought for decades. However, this neural signature is also not incompatible with other processes associated with acquisition of language in social environments. This leads us to address the importance of the social element for acquisition of our primary language (L1), and, in addition, a second language (L2).

## A brief analysis of the difference between first and second language acquisition

As mentioned earlier, the acquisition of L1 differs from that of L2. That difference is rooted in the pattern and timing of stimuli first introduced and then established when learning the primary language (FRIEDERICI, 2017). Before birth, our ears are primed while in utero by the melody of our mother's speech and we begin to attend to the sounds and the contours of the language that will eventually surround us (MAMPE *et al.*, 2009; WERMKE *et al.*, 2017). This process shapes our brain circuitry and our vocal apparatus which, as noted before, comes preset to function according to any variety or combination of human speech.

Once we acquire the contours and manage to produce spoken language according to a set of patterns (that of L1), we will continue to develop proficiency according to syntactic rules and accepted semantics in a manner shaped by our prior experience (YEUNG; WERKER, 2009; YOSHIDA *et al.*, 2009). This *schema of previous experiences* determines the way that our brains process the incoming input and produces the output in any given language.

Although whether a critical period exists for normal acquisition of L1 remains inconclusive, acquisition of a second language is possible at any subsequent time, though the level of proficiency with regard to syntax and meaning may not reach the level of a native speaker (FRIEDERICI, 2017). Research points to the presence of a sensitive period for the acquisition of a primed vocalization pattern for other languages (KUHL, 2000; 2004; 2010). Kuhl has demonstrated that babies exposed to sounds, via human interaction, of a language other than his/her L1, remained ready to produce the sounds of said language with native-like prowess later in their development. We can learn an L2 at any age, although with more difficulty, and the same more or less holds true for any academic ability, i.e. ones that are typically acquired in a school setting, for instance.

## Understanding language development through research on dyslexia and aphasia

The fact that our vocalization apparatus and neural systems can be primed for the production of meaningful speech in any of the more than 7,000 known languages (SIMONS; FENNIG, 2018), including creole and pidgin languages, gives us a rough idea of the complex operational processes needed to produce language. These can be jeopardized, however, when processing pathways, are wired in atypical ways. This is the case for those affected by dyslexia, for example (VALDOIS; BOSSE; TAINTURIER, 2004). Neural signals necessary for reading written language do not follow the same processing pathways that exist in typically developing children, thus learning to read becomes much more difficult. Although it is commonly misunderstood to be a problem primarily and solely associated with visual perception of words, it is also linked to differences in auditory processing of spoken language.

An individual with dyslexia, a condition which should be understood as a variation in neural processing, presents a deficit in the mental manipulation of phonemes, that is, a deficiency in the awareness and treatment of individual speech sounds related to visual spatial atypical attentional processing (VIDYASAGAR; PAMMER, 2010). Studies have examined the possibility of a genetic basis for this deficiency (FISHER; DEFRIES, 2002; FISHER; FRANCKS, 2006) and it can vary with respect to the nature and degree with which it presents, i.e., an individual with dyslexia can process either, or both, auditory and visual inputs in atypical ways.

Although research has identified variations in neural circuitry among individuals with dyslexia, there is no reliable biological test for dyslexia. The diagnosis relies on behavioral measures and can be identified by the presence of difficulties impeding routine processing of written language to the exclusion of many other possible causes, such as ASD (Autism Spectrum Disorder), hearing loss and speech disorder.

The study of dyslexia has shed a new and broad-spectrum light onto the understanding of the neural processing for language. By looking into the difficulty dyslexics have in processing phonemes, we are better equipped to reconceptualize the heightened importance of reading readiness in terms of phoneme awareness, phoneme processing and, later on, phoneme and grapheme identification.

Our earliest understanding of brain regions important for language processing is derived from patients with aphasia, through studies completed decades ago have revised the classical view developed by Broca and Wernicke (CARAMAZZA; ZARIF, 1976). Broca studied patients with different types of aphasia and performed post mortem studies demonstrating that problems with speech production and comprehension involved structures in the left cerebral hemispheres (KANDEL *et al.* 2000). Caramazza and Zarif (1976) applied contemporary linguistic theory to show that Broca's patients not only had trouble producing speech, but that the speech they did produce was agrammatical, uttered in a telegraphic manner and without function words that typically signify relationships among words. Though comprehension was intact for simple constructions, they had difficulty with complex sentences or passive constructions, which requires interpretation of these grammatical relationships.

A similar but reciprocal change occurred in interpretation of the role played by Wernicke's area in the temporal cortex (MILBERG; BLUMSTEIN; DVORETSKY, 1987). Wernicke's patients with lesions in the temporal cortex had difficulty with comprehending speech, but also had trouble choosing the words they spoke and incorrectly naming pictures of objects. Though researchers argue about the finer points of these interpretations, they are generally in alignment with the existence of a central knowledge base for grammar and a central lexicon for word comprehension (FRIEDERICI, 2017).

In most cases, aphasia results from a cerebrovascular accident (CVA), or stroke, but it can be a consequence of any form of trauma. It takes different forms according to which area of neural processing is affected by the accident (DRONKERS; BALDO, 2010). Based on observation of the distinct speech patterns of aphasic patients, researchers have demonstrated that extensive neural networks respond to specific processing of the distinctive features of language. The often-remarkable functional recovery of many patients also demonstrates that brain regions outside the affected area can take over processes necessary for language, thus reflecting the plasticity and adaptability of our neural circuitry (DI PINO *et al.*, 2014; HAMILTON; CHRYSIKOU; COSLETT, 2011; THULBORN; CARPENTER; JUST, 1999).

## Conclusions

This literature review has focused on presenting an overview of developmental processes important for acquisition of language and higher-level cognitive skill inextricably connected to thought. We presented a short discussion of how language shapes our thinking as well as the developmental course it follows. We provided an example of how language development is primed during gestation to promote readiness for auditory processing of one's mother language and how distinct in development and readiness language abilities are. These are deeply rooted in our biological makeup, via our genome, which provides a platform for language acquisition via establishment of neural systems that adapt and reorganize in response to input. Language processing systems, and, perhaps consequently, our world views, are heavily influenced by the scope of possibilities offered by human experience.

In considering second language acquisition, we discussed how L1 learning is different from L2 as well as possible sensitive periods that affect their development. Finally, we have included a section on how research on the atypical processing of language in the face of deficiencies, such as dyslexia and aphasia, has shed light on the understanding of linguistic processing.

In our role as educators, rather than researchers, we are not in a position to take a firm stand on where to place comprehension and production of speech on the innate vs learned continuum. Evidence is clear, however, that acquiring language skills to communicate wants and needs appears in early years in a manner that seems as natural as learning to walk. Notably, however, acquiring the ability to effectively communicate one's abstract thoughts and opinions and to understand those of others requires interactions within a social substrate throughout a lifetime. Social relationships, formal instruction, and the culture within which we are immersed shape the development of our cognitive abilities and our conceptual view of the world through the medium of language. These abilities arise as a consequence of a constant interaction between the environment and the genetically determined neurobiological system that is responsive to and modifiable by external input while operating to maintain a state of homeostasis in body and mind.

## Final considerations

We remind the reader that current neuroscience research is on the verge of scientific breakthroughs that may restructure our understanding of how our neuronal processes shape our cognitive processes and behavior. Jeff Lichtmann, who is Jeremy R. Knowles Professor of Molecular and Cellular Biology and the current Ramón y Cajal Professor of Arts and Sciences at Harvard, leads a team carrying neuroscientific research to understand neural connectivity and how it changes with development. He stated that we do not presently possess the different tools to unravel the mysteries of some of the higher functions performed by our brains (SERIOUS SCIENCE, 2014)**.** While we all marvel at the complexity and beauty of the human brain, we need to be humble and learn how to deal with uncertainty. Caution and care in the treatment of information that stems from the lab is called for and it is incumbent on us to make that a constant in our minds and in our teaching.

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