

## Neuroscience role in the foreign language teaching and learning

*O papel da neurociência no ensino e aprendizagem de língua estrangeira*

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### Resumo

Este artigo pretende estabelecer uma conexão entre a neurociência e o ensino e aprendizagem de uma língua estrangeira; começando por uma introdução do assunto; em seguida apresentando uma visão geral de quais áreas do cérebro estão relacionadas à linguagem, as conceituações da neuroplasticidade e os diferentes conceitos da hipótese do período crítico e sensível. Após, é realizada uma análise de quais contribuições a neurociência fez no campo de ensino e aprendizagem de línguas, bem como de que modo essas contribuições podem ser adaptadas e aplicadas em uma sala de aula de língua estrangeira. Concluiu-se que a neurociência pode ser capaz de apoiar as metodologias do professor, a fim de melhorar suas técnicas e facilitar o aprendizado dos alunos.

**Palavras-chave:** neurociência; neuroeducação; período crítico; língua estrangeira; metodologias de ensino e aprendizagem.

### Abstract

*This paper intends to establish a connection between neuroscience and the teaching and learning of a foreign language. It starts with an introduction of the subject, proceeding to an overview of the brain areas related to language, the conceptualizations of neuroplasticity and the different concepts of the critical period and sensitive period hypothesis. Then, the contributions of neuroscience has made in the language teaching and learning field will be analyzed, as well as how these contributions can be adapted and applied to a foreign language classroom. It was concluded that neuroscience might be able to support the teacher's methodologies in order to improve his/her techniques and facilitate students' learning.*

**Keywords:** neuroscience; neuroeducation; critical period; foreign language; teaching and learning methodologies.

### Introduction

Understanding the brain's functionality is crucial to understanding the language-learning process. According to neuroscience, language is not located in a single place of the human body; it involves different structures, distributed in different areas of the encephalon, for example, the right and left hemisphere, the dorsal and ventral parts of the brain or the articulatory system. Thinking about the language teaching and learning, this complexity of the language system reflects about the process of teaching a foreign language in order to focus on its functionality, aiming the development of the structures involving language learning in each person.

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When we talk about brain functionality, we have to talk about neuroscience studies. By using neuroscience studies we can have a different idea of what means to teach, and especially, to learn another language.

The objective of this paper is to analyze the possibility of using neuroscience to support pedagogical practice in the foreign language classroom to improve teachers' methodologies and to facilitate students' learning. By this analysis, it is also intended to study what neuroscience says about the language-learning process. By using the contributions of neuroscience, teachers may be able to improve their methods and class organization, focusing on the functionality and effectiveness of their teaching.

This research is a bibliographic review, based on papers mostly published between 2000 and 2017. Because the discussion about the connection between neuroscience and education is recent, there is not a considerable amount of older material containing accurate information on the theme proposed. Therefore, the criteria for this selection is based on the accuracy of the information brought by these papers, since the most recent data about the theme are found in studies and research from the academic background.

## 1 Neurobiological basis of language

### 1.1 Brain structures related to language

According to Stiles and Jernigan (2010), our brain is formed by more than 100 billion neurons. These neurons are cells that process information in the brain, and they vary in size, shape and function. Neurons establish connections among them to form and process information.

Information is transferred by electrical signals, creating points of contact with other neurons, forming networks. Sinani (2012) says that such networks are formed by groups of cells, named "neuro-functional scheme". The activation of these neurons could be influenced by a genetic factor, such as, for example, our ability to cry as a baby. Genetic activation involves the human functions that do not have to be learned, our behaviors, which are natural for everyone. Other cases of neural-function schemes will depend on the input of the environment or/and the person who gives these inputs. Language is related to both activations: genetic activation, because of our necessity and predisposition to communicate, and activation by the inputs received, because of our necessity to improve language to be understood.

To Friederici (2011), this language network means that each area is responsible for one process, and these areas are interrelated to express a language at the end of the processes. The main regions are Broca's area and Wernicke's area and, in these areas are specified subregions to process language.

Friederici (2011, p.1358) stated that Korbian Brodmann was the first to establish a description of the human cortex. The neuroarchitectonic brain provided by Brodmann suggested a division of Broca's area in adjacent areas. By these suggestions, area 45 is subdivided into an anterior area (45a) and a posterior area (45p) bordering the 47 area. Area 44 is also subdivided in a dorsal area (44d) and a ventral area (44v). These subdivisions may be a result of different language experiments that have designated different functions to the area 45. The same may happen to the area 44. The Inferior Frontal Gyrus (IFG) connects the area 44 to the temporal cortex via a dorsal pathway and the area 45 with the temporal cortex via a fiber system.

Broca's area is connected with Wernicke's area by a dorsal and ventral pathway. The ventral pathway is responsible for supporting the transformation of sound in meaning while the dorsal pathway is responsible for supporting auditory-motor integration. Also, the dorsal pathway has another function: to support the processing of non-adjacent elements in complex sentences. Meanwhile, the ventral pathway has the function of supporting combinations of adjacent elements in a sequence. By this analysis, it was concluded that there are two dorsal pathways, one from the temporal cortex to the premotor cortex and one from the temporal cortex to area 44. Moreover, there are two ventral pathways, one connecting the frontal to the temporal cortex and other connecting the area 45 to a fiber capsule system

Friederici (2011, p.5) stated that the division of two dorsal pathways is present in very young children. The dorsal pathway from the temporal cortex to the area 44 is developed later. It means that, first, our brain develops ways to receive and emit sounds and, as they were developed, it is time to find ways to understand these sounds and give meaning to them.

Talking about specific neural networks, it is important to know the processes that involve the language network. The most relevant language processes are related to the auditory input, acoustic-phonological, syntactic and semantic comprehension. As stated by Angela D. Friederici (2011), when talking about spoken language, the comprehension starts with the acoustic-phonological analysis of the speech input. The sounds of a speech are processed on the Planum Temporale (PT) and on the Heschl's Gyrus (HG) Friederici (2011, p.1363) concluded that the HG is responsible for analyzing the sound signal perception, and the PT is responsible for categorizing the sounds and serving as a computational hub to get information. The primary auditory cortex (PAC) responds to speech and tonal pitch. However, it is divided by the left and right hemisphere. While the left PAC react to speech sound characteristics, the right PAC react to tonal pitch characteristics. So, according to Friederici (2011), the processes step for auditory language comprehension starts on PAC and distribute the information in two directions, the PT and the HG.

In addition, syntactic and semantic processes are correlated. As stated by Friederici (2011), at first the listener or the speaker needs to organize a sentence syntactically in order to understand it semantically. The most activated areas are in the anterior and posterior cortex and at the IFG (Inferior Frontal Gyrus). Firstly, the activations of the temporal cortex will be considered and after the IFG activations. The role of the temporal lobe (temporal cortex) has different functions for different authors.

The posterior temporal lobe was also identified to be activated for language comprehension. Friederici (2011) analyzed that the left posterior superior temporal gyrus (STG) reports the syntactic information comparing sentences to word lists and comparing sentences with syntactic violation and syntactically correct sentences. In conclusion, Friederici (2011) stated that the posterior temporal lobe is more activated for the syntactic process, especially when talking about word order and verbs relations to its arguments.

Furthermore, it was found that the brain's activation could be also related to the origin of the language. In her analysis of different Indo-European languages, Friederici (2011) observed that all followed a subject-verb sentence order. Friederici used the term "canonical"<sup>1</sup> to refer to this language structure. The study's methodology applied canonical and noncanonical sentences and analyzed the brain activations for each structure. In both cases, the Broca's area was most activated during the interpretation of these sentences. As the result, Friederici (2011) concluded that Broca's area is essential for processing syntactic, mainly in syntactically complex sentences. In addition to Broca's area, the left dorsal posterior IFG, the Inferior Frontal Sulcus (IFS) and the mid-posterior Superior Temporal Sulcus are also activated by syntactic complexity (Friederici, 2011). Nevertheless, there is a moment when

semantic and syntactic suffer an integration to achieve interpretation. Neuroscience studies showed that this integration occurs specifically on the Superior Temporal Gyrus (STG), but not only there. To Friederici (2011), the semantic and syntactic integration's area depends on its level of integration. The author stated that the final integration occurs on the left posterior STG but first the integration of relevant language information is located on the left IFG (Inferior Frontal Gyrus).

Beyond the syntactic and semantic processes, is the prosodic process. Friederici (2011, p. 1375) explains that our brain distinguishes two types of prosodic information, the emotional prosody, and the linguistic prosody. However, the author chose the linguistic prosody as a matter of study. The prosodic interpretation depends straightly on the intonation of the speaker; by the intonation, the listener will analyze which order the information follows in a sentence. The authors stated that linguistic prosody is more processed in the right hemisphere (RH). Nevertheless, the left hemisphere (LH) is also involved in the prosody process, but with less relevance and activation.

Other important processes are the acoustic-phonological, syntactic and semantic. The acoustic-phonological process, in summary, is the analysis of speech sounds and interpretation of meaning on the spoken language. The semantic process also takes care of meaning, however not only on spoken language.

Intending to accomplish the second objective of this section, explaining the relations among different brain areas and structures, clarifying the functionality of the language network, it was used Dick and Tremblay (2012). The authors discovered other fiber pathways for language processing beyond dorsal and ventral pathways (fiber pathways<sup>2</sup>). Dick and Tremblay (2012) affirm that there is a connection between the dorsal pathway and the superior longitudinal fasciculus/arcuate fasciculus (See Figure 7); in the ventral pathway, they also discovered different connections. For Dick and Tremblay (2012), these connections occur between the uncinate fasciculus, the inferior longitudinal fasciculus, and the inferior fronto-occipital fasciculus. In the dorsal pathway, the superior longitudinal fasciculus/arcuate fasciculus establishes the connections between the reception and expression of language. This connection works by the co-relation of Wernicke's area, in the left temporal lobe, with Broca's area, in the left frontal lobe, especially by the arcuate fasciculus.

In the ventral pathway, the uncinate fasciculus connects the anterior temporal areas to inferior frontal areas. This fasciculus is associated with semantic processing and auditory working memory (WM), which means that the uncinate fasciculus is responsible for analyzing sounds and its intentions of the speech by emotional significance. The extreme capsule is also related to the semantic process, however, by the connection of the inferior frontal gyrus and the superior and middle temporal cortex, the extreme capsule has the role of storage semantic information. The middle longitudinal fasciculus is known as a white matter tract that connects inferior parietal lobe with temporal cortices (Dick & Tremblay, 2012, p.3539). By this connection, the middle longitudinal fasciculus is responsible for the comprehension of speech sounds as well as to carry information from primary to secondary auditory association. Instead the uncinate fasciculus, the extreme capsule, and middle longitudinal fasciculus; the inferior longitudinal fasciculus and the inferior fronto-occipital fasciculus do not have a clear interpretation of their functions and relevance to language.

Nevertheless, it is important to mention that these fiber pathways are being studied and analyzed to get a conclusion of how they really work and to which language function they are associated. Until now, the functions mentioned before are hypothesis developed by the strong evidence found by neuroimaging procedures analyzing people that suffer from some aphasia or some lesion in the brain language areas. Also, different authors disagree among

each other in some points, making it difficult to establish a conclusion. So, this is a topic that needs more analyses and attention to develop a certain understanding of their functionality in language processing.

To facilitate the understanding of the reader, the main brain regions, structures, and fiber pathways were summarized in Tables 1 and 2. Table 1 is about the brain regions and structures functions and Table 2 is about the fiber pathways functionality and importance.

Table 1 – Summary: Brain areas and structures functions for language

<i>Brain area/structure</i>	<i>Functions for language processing</i>
<b>Broca's area</b>	Essential for syntactic processing
<b>Wernicke's area</b>	Essential for semantic processing
<b>Heschl's Gyrus (HG)</b>	To compute the first auditory inputs
<b>Planum Temporale (PT)</b>	To compute phonetic sounds
<b>Left primary auditory cortex (PAC)</b>	To react to speech sound characteristics
<b>Right primary auditory cortex (PAC)</b>	To react to tonal pitch characteristics
<b>Anterior superior temporal gyrus (STG)</b>	To process syntactic and semantic information
<b>Inferior frontal gyrus (IFG)</b>	Responsible for the motor reproduction of language and for the working memory process
<b>Superior temporal gyrus (STG)</b>	Responsible for the integration between semantic and syntactic information
<b>Right hemisphere</b>	More inclined to process prosodic characteristics in speech
<b>Left hemisphere</b>	More inclined to process sentence structure characteristics

Source: Created by the authors, adapted from Friederici (2011).

Table 2 - Brain fiber pathways functions for language summary

<i>Fiber pathways</i>	<i>Functions for language processing</i>
<b>Ventral pathway</b>	To support the transformation of sound in meaning
<b>Dorsal pathway</b>	To support auditory-motor integration
<b>Superior longitudinal fasciculus/arcuate fasciculus</b>	To establish the connections between the reception and the expression of language.
<b>Uncinate fasciculus</b>	To connect the anterior temporal areas to the inferior frontal areas; to analyze sounds and emotional tone
<b>Extreme capsule</b>	To connect the IFG and the superior temporal lobe; to storage the semantic information
<b>Middle longitudinal fasciculus</b>	To connect the inferior parietal lobe with temporal lobes; responsible for the comprehension of speech sounds and for carrying information from primary to secondary auditory association.

Source: Created by the authors, adapted from Dick and Tremblay (2012).

## 1.2 Neuroplasticity and critical period

Our brain's ability to change functionally and physically is called neuroplasticity or brain plasticity. This plasticity is activated by the environmental stimulus, and by the plasticity,

our brain adapts itself to different situations. It is because of this ability that some people can recover damages suffered by brain lesions. Not only this, plasticity is related to our ability to learn new things also.

First of all, it is important to understand neuroplasticity and its relation to language. Li, Legault, and Litcofsky (2014, p.2) observed that during the development of a second or foreign language – in this section, for both will be used L2 – always occur anatomical changes in brain structure. These changes are commonly an increase of gray matter (GM) density and white matter integrity; according to the authors, the increase of both matters is also related to the age of the learning of L2.

To help our understanding, the authors first explained the relation between brain changes and functional neural activity patterns. The authors analyzed the gray matter density in different areas related to language. The areas showed a considerable increase of gray matter when the person was learning an L2 or when the person was already bilingual, comparing it to a monolingual person.

Another topic Li, Legault, and Licofsky (2014, p.14) studied was the time taken by our brains to adapt and change for the L2 code. The authors found out that it depends on the kind of stimulus applied to the L2 teaching and learning methods. In recent research, Li, Legault, and Licofsky (2014) discovered information stating that the first and considerable brain changes may occur about the first three months or even at the first seven days in contact with the L2. Further, the author found some evidence showing results of brain anatomical changes and gray matter increases on the first two hours of the L2 learning. Nevertheless, the authors noticed that the different results also used different techniques and levels of exposure to language.

In addition to the Li, Legault, and Licofsky (2014) information, Zhang and Wang (2007) stated that the changes in brain structures mean changes in neurochemical systems, cell connections, brain activation and even behavioral performance. These structures' changes implicate in psychological development, language intervention, and neural rehabilitation. For Zhang and Wang (2007, p.154) neuroplasticity is also related to genetic factors. It is also important to mention that plasticity is not a malleable phenomenon and you cannot stimulate your brain to be more plastic along life. As well, plasticity is individual and can be longer or shorter, depending on the person.

In the other hand, there is a critical period hypothesis, which, against the idea that there is no timeframe for neural plasticity, affirms that after some moment in life it is not possible to acquire a new language. It is relevant to mention what is the relation between critical periods and neuroplasticity. These concepts interact with each other because of a relationship that is established in dated studies. Conforming to these studies, the critical period ends at the puberty or the end of adolescence, when, for the authors that confirm this theory, is the time that neuroplasticity starts to decrease. Opposed to this theory, some authors state sensitive periods for L2 acquiring and learning. As mentioned by White et al. (2013, p.1), it is not possible to mix the terms. For the authors, critical periods define short and specific *windows of opportunities* to the L2 learning, causing irreversible brain structures and functional changes. The sensitive period, however, is defined as gradual changes in brain structure and functions, in which the learning still possible after some age point or after the L1 acquiring.

White et al. (2013) established their article analyzing the L2 learning and plasticity during and after a sensitive period. The sensitive periods are defined as starting from birth to late adolescence, being strongly present in the first four years of life and a little bit less present over the years. As we are born, our brain is developing, and the inputs received have a big role

in this development. In the first four years, the first language code is formed; this code will be improved along the whole life, improving our language skills. If the individual grows up bilingual, both L1 and L2 will have their language code developed at that time and the process will be the same for both languages. Different from people who learn the L2 after the L1 code was formed, in these cases more brain effort and changes are needed. The time mentioned before has the most sensitive period presence because of brain maturation, which results in neuroplasticity high levels. As reported by White et al. (2013, p.4), brain maturation results in declining of synaptic density<sup>3</sup>, decreased levels of brain metabolism, and increase of axon myelination<sup>4</sup>.

White et al. (2013, p.2) explain that plasticity during sensitive periods works as a bottom-up process<sup>5</sup> and along the time of contact with the second or foreign language the neural representations become selective, it means, this structure is more focused on the relevance of the information for the aiming it is looking for. The authors affirmed that this “adaptation” is rapidly created and responds directly to the environmental stimulus. The plasticity after sensitive periods was described by the authors as a top-down process<sup>6</sup>. For instance, as we grow up, we adapt our brains to receive and interpret information, not analyzing sentence structure or words meaning individually.

Different from Li, Legault, and Licofsky (2014); Zhang and Wang (2007) and White et al. (2013), Birdsong (2006) defends the idea of a critical period in L2 acquisition and learning. The author analyzed the aspects and the results between the age of acquisition and the success of the speaker L2 fluency.

To make his review, Birdsong (2006, p.15) considered three hypotheses of the critical period end. The author analyzed it as if the critical period had only one high point; after, it starts to decrease until a finite point, where the person will have the same plasticity and capacity for the rest of its life. The second hypothesis is that the critical period follows the same line during a period of time and, after, starts do decrease until the person life's end. The third hypothesis is a mix of the first and second. The observation made by Birdsong (2006) results in a persistent decline in L2 performance – fluency and success – as it increases the age of the learner – age of acquisition and learning. However, in the first analysis, Birdsong (2006, p.17) could not specify which of the hypothesis mentioned before is the real, the previous conclusion is that it exists a decline of plasticity and learning capacity over the age of the learner.

After a deeper analysis, Birdsong (2006) concluded that the only hypothesis possible to the critical period is the second, which describes the neuroplasticity as a line and this line starts to decrease after brain maturation. Nevertheless, the decrease of neuroplasticity and ability to learn things does not have a finite point. In other words, after our brain achieves its maturation, the capacity to change and adapt starts to fall down and keeps falling for the whole life. The author defined the high level of plasticity as a window of opportunity and stated: [...] the temporal span during which sensitivity or learning potential is at its highest and full attainment is guaranteed (Birdsong, 2006, p.17).

In conclusion, it is possible to notice a similarity in the findings of Birdsong (2006) about the critical period and the other finds about the sensitive periods. The sensitive period hypothesis has stronger evidence of existence and more plausible reasons than the critical period. Although none of the hypothesis has a verdict about its nature.

As some concepts of this sections are very similar, in the same way that they diverge among themselves, it was elaborated a table (Table 3) comparing and summarizing the main idea of each concept, as well as its relation to language.

Table 3 – Concepts and its relation to language summary

<i>Concept</i>	<i>Conceptualization</i>	<i>Relation to language</i>
<b>Neuroplasticity</b>	The brain ability to change and adapt functionally and anatomically after brain lesions or for the acquisition of new knowledge. Plasticity is individual and its duration depends on genetic factors. It is known to decrease over the years.	Studies that analyzed L2 acquisition and learning found increases in gray and white matter during the process. These increases were a result of neuro-architectonic changes in the brain of the learner.
<b>Critical period hypothesis</b>	The period of life when neuroplasticity is at its high levels and brain is capable to adapt and change.	The critical period hypothesis states that after the ending of a critical period it is not possible to acquire and learn an L2 anymore.
<b>Windows of opportunity</b>	How critical periods are called and defined.	There are three hypothesis of windows of opportunity timeframe for language: one (a) states that it starts from birth until puberty, other (b) affirms that its duration is from birth to late adolescence and the third (c) defines the ending of the window of opportunity when brain achieve its maturation, which could vary among people.
<b>Sensitive periods</b>	The latest hypothesis of the critical period. It is defined as the period of life in which an individual has easiness to acquire new knowledge, not being impossible to learn after the ending of the sensitive period.	More recent data discovered that there are sensitive periods for L2 acquisition and learning. The sensitive periods also depend on the aspect of language being analyzed and agree that, as well as neuroplasticity, its timeframe is individual, and depends on the genetic factors of the person. It is known that, during a sensitive period, the L2 learning depends on external inputs and, after the sensitive period, the L2 learning depends most on the person conditions.

Source: created by the author using as a basis Li, Legault, Litcofsky (2014), Zhang and Wang (2007), White et. al (2013), Birdsong (2006)

By observing Table 3 it is understood the importance of neuroplasticity in the language learning process and the relation of plasticity and critical periods or sensitive periods. This relation is that all the concepts state their timeframes or periods of easiness in L2 acquiring and learning to plasticity levels, for example, decreases and increases in white and gray matter. The biggest difference between the critical period – windows of opportunity – and the sensitive periods is the finite point, which exists for those who defend the hypothesis of a critical period for language, affirming that it is not possible to learn an L2 after this point. For those who defend the hypothesis of sensitive periods there is not a finite point to language learning, instead, there are moments in life in which a person may have easiness to acquire and learn the L2.

## 2 Applied neuroscience contributions in the foreign language teaching and learning

This section intends to – by the use of neuroscience discoveries and the analysis made in the previous sections – establish an overview of how neuroscience can contribute to teachers' methodologies and facilitate the teaching and learning of a foreign language. Finding ways to use neuroscience as a support for teachers' methodologies and use neuroscience contributions in order to explain different ways to learn an L2.

According to Guy and Byrne (2013, p. 40) the learning process involves, obviously, the working memory (WM) and the long-term memory (LTM), as well as the prefrontal cortex (PFC), the anterior prefrontal cortex (APFC), and the dorsal and ventral lateral prefrontal cortex (DLPFC and VLPFC). To the authors, in an educational environment, the process of stimulating the WM and achieving the comprehension of what is being learned can be helped by applying tasks in which students will focus only on the point of the study, without distractions.

However, the WM and the LTM do not have a simple connection. Although the WM is important for gathering the information at the same point it is being received, the LTM is primordial for the storage of it. As stated by Guy and Byrne (2013), there are different types of LTM, for example, the semantic memory, which stores the facts and associates it to others knowledge, creating a semantic framework. By this framework, it is formed the basis of thought and learning, resulting in the effectiveness of the learning. Here the authors affirm the importance of the activities to provide relations among previous knowledge.

Another aspect that teachers can apply in their classroom, as stated in Guy and Byrne (2013, p. 41) is default tasks, that is, tasks where students should think about what is missing and establish the association among concepts by themselves. The authors also suggest for teachers to work with students in groups in this sort of activities, so they could share their knowledge and built new networks. Complementing their studies, the authors found that metacognition is a result of increases in gray matter volume in the association prefrontal cortex (APFC) and the dorsal lateral prefrontal cortex (DLPFC). Metacognition is important during the learning and teaching processes because the self-conscious of the learner and his/her ability to judge their own mistakes.

Further the analyses by Guy and Byrne (2013), Kuhl (2011) studied the language learning process in young children, focusing more on the acquisition of a second or foreign language. The author stated that the first learnings of a child are a result of implicit inputs that happen by the interaction of the child and the external environment; however, in the language process, to develop these inputs the child needs a nice social interaction with another human being, which will determine the levels of the child language.

Kuhl (2011, p.136) affirms that, to help the second language acquisition during childhood, it is important to think about how effective it will be for the child, for example, if the exposure given to the language is good enough to develop the language patterns fluently. The amount of people with whom the child will get in contact that speak that language is important, also, for the child to have enough social interaction and basis to use that language and to develop its code. As well, even more important is the separation of the languages: for the child it is important to clarify with whom he/she is going to speak each language. This is important to the child does not mix both language codes and confuse what is each one of the languages. The results of starting earlier in the second or foreign language learning is an "open mind" for language development further in the child's life.

Moreover, Kuhl (2013 p.137) established a comparison of younger bilinguals and adults who have learned a new language at some age after childhood. The author found that, in both cases, there are similarities in the methods that should be used in the teaching and learning processes. The evidence provided by the studies are the importance of the experience in the language learning process. Students showed advanced skills in the L2 when the methodology used put them in contact with the language. There are different ways in which this contact could be established. An idea is to put students to role-play some dialogues or even create their own to, after, present it to the class. Another idea is to apply activities in which students can get in touch with phonological aspects of language, interact with spoken language, like listening activities. The author also remains the importance of the teacher to be aware of how reflexive are the activities proposed, because it needs the students to concentrate on it too.

In conclusion to the authors analysis, the concepts of critical or sensitive periods can help in the language teaching and learning process because of the moments in which we know an individual can have easiness in acquiring a foreign language as well as when the plasticity is in its high levels. Kuhl (2013) stated that the best moment to start to learn an L2 is the childhood. Moreover, it is also important to work with language in the more social way possible because, in this moment of life, our brains are more social and depend on the external environment to develop different skills.

Munakata, Casey, and Diamond (2004), in addition, present differences in the brain learning activity depending on the age of the learner. The authors observed a better capacity to focus and to be involved for a long time in behavioral tasks in children and adolescents. Munakata, Casey and Diamond (2004, p.123) likewise explain that these variations in the kind of activity that responds better according to the age are not related to the experiences suffered, but rather a result of synaptic brain maturation and changes in neural connections.

Relating the perspective of developmental cognitive neuroscience to the language learning process, the authors stated that, the less developed are the brain structures, the easier is for the individual to acquire a second or foreign language. This information complements the hypothesis of critical or sensitive periods in the language acquisition and learning process. Munakata, Casey, and Diamond (2004) explained that the existence of a sensitive period in the language field might actually be a result of less mature and developed brain structures.

Bringing it to a classroom perspective, teachers should considerate students' age before planning more dynamic or calmer activities, according to the stage of the learner and his/her age. As important, it is to analyze the student personality. By the individual behaviors, it is possible to have an idea if he/she are more mature – cognitively developed, in this case – or not. The best way to work with it is going slowly and being much focused on which language patterns teacher and learner expect to achieve.

Summing up, Munakata, Casey, and Diamond (2004, p.124) stated that cognition, perception and emotion are strictly connected in the learning process. They observed that, in stressed situations, the levels of dopamine<sup>7</sup> decreases, difficulting the neurotransmitter systems work. As well, in rude and authoritarian social relations, children showed difficulties in perceptual and attentional abilities, compromising the learning effectiveness.

Additionally, to Munakata, Casey, and Diamond research (2004), Nergis (2011) also studied the connections among neuroscience, education and social environments. Nergis (2011) mentioned that in some way the approaches used for the L2 in a teacher's methodology should be closer to the manner in which the students use the L1. In other words, this means that the second or foreign language should be taught in a more practical way. According to the author, it is important to follow the order communication-grammar in the

language classroom; putting students to practice different language patterns like in a real situation, instead of only explain complex grammar structures.

Further, on Nergis (2011) studies, it was observed that students have a big difficulty to automatize the second or foreign language patterns. The author stated that a solution to it is the teacher to use the L2 as a communicative role in the classroom, it means, talks in L2 with students. The author also mentions the importance of the limbic system in the foreign language classroom. Nergis (2011) said the limbic system is responsible for emotions and motivation. These patterns regulate the cognitive conditions to learn, resulting also in the ability to pay attention to the message being transmitted. The author also stated the importance of metalinguistic in the L2. Nergis (2004) affirms that, when the individual learns the L2 in a formal environment, he/she develop more metalinguistic knowledge and teachers can help this development by making students conscious of his/her mistakes and consequently reducing them.

Alonso (2017) also studied the cognitive neuroscience. In accordance to the author, mostly of affirmations made about cognitive neuroscience need deeper analyses and are mostly relations established by brain regions and structures activations during the learning of a subject – language learning. In the case of this paper, we focus on ways in which it is possible to activate this regions and structures and manners to approach this in the class planning.

Moreover, Alonso (2017, p.21) affirms that the process of turn short-term memory into the long-term memory is a result of the social interactions. She stated that according to the inputs received by the person, his/her cognition will judge the relevance of it; the more is the input received about the same topic, the most important the information will be considered. Consequently, the brain will pay more attention to it and turn the information into long-term memory.

Complementing her research, she analyzed the mechanisms used by the brain to acquire and learn new languages along life. To the author (2017, p.31), we are born with the ability to comprehend any sound and learn any language. This ability is almost lost at one year after birth and decreases over the years. In addition, the researcher stated that different language patterns have different learning process and brain structures involved. For instance, the reading ability is not a natural thing for our brains and, therefore, it is not pre-determined by our genes and it is adapted along our life depending on the needs of the person.

Conforming to Alonso, it can be learned by phonological aspects, using the sounds as a basis to comprehension, or by visual recognition of words, using the visual abilities of the learner as a basis to establish the comprehension. It is important to say that there is not a better or a right way to teach and learn reading aspects. It is necessary to know if the student is more visual or more acoustic and, by this, establish the way in which the teacher will approach the reading in the L2 classroom. In big groups, the teacher's dare is even more difficult, so the best way to work with reading classes is by approaching both methodologies, in order to access students from different conditions and levels of learning.

Continuing her review, she established a list of contributions that neuroscience has made for supporting the teachers' teaching techniques. One of the topics the author explained was related to the emotional of students. She stated that we can use the information of neuroplasticity to stimulate students and demystify some believes that could put students down and difficult the learning process. Moreover, neuroscience studies have told us that emotions influence the learning process in a very considerable way. So, teachers should try to understand and deal with students' emotions, in a manner that it will be possible to develop a comfortable environment to the learning, as well as help student's motivation to the L2 learning.

Following the author's list, it was also mentioned the importance of caring about sleep hours, because, in sleep hours, our brain is able to reorganize itself and consolidate the memory, selecting what is more or less important and storing it in short or long-term memory. Also, the researcher affirms that the maturation of the executive control system is relevant to language development. She stated that teachers should use activities that stimulate the students' self-control and the ability to focus on objectives. Example of this sort of activity is to promote debates in the classroom, in which students have to agree and disagree with something, using the L2; however, establish rules to the speaking time, like to point convincing arguments, not being exalted and not losing the objective of the topic he/she is defending.

Another important topic presented in Alonso's (2017) list was the self-evaluation of the teachers' methods. The researcher also advises teachers to organize tasks that progressively increase the levels of difficulty to students do not accommodate in a comfort zone and becomes lazy in the language learning – the increases of the inputs' complexity need to be constant. As well, the author proposes teachers to work with activities that involve different sensorial areas, like listening, reading, speaking or even dynamics that require students' movement. According to the author, these tasks are more significant and facilitate the memorization of the information.

Furthermore, Alonso mentions the age of learning in her review, either, nevertheless, in other perspective. There are two aspects analyzed on the teaching and learning of an L2. One is *on route* and the other is *rate*. *On route* aspect is related to the different stages of the learning of a foreign language and *rate* is related to the quickness that the learner crosses each stage. To Alonso (2017, p.41) the age influence on L2 is the *rate* aspect. It means, the earlier the person starts to learn a foreign language, the faster the learner will cross the stages of learning.

Moreover, the author brought to us the concept of interlanguage. Interlanguage means the language aspects developed during the start of the second or foreign language learning until the student achieve fluency on this. For her, this is an individual aspect because each student will develop the interlanguage differently. For instance, the author stated that students do not use to memorize the rules of the language being learned as it is taught to them; however, they use to create their own rules, by associations made with the mother language or previous knowledge. Teachers should observe and help on what association students are making during the class, evaluate how able they are to create their own rules of the language and what is contributing for them to get to the conclusion they established.

Additionally, to the studies analyzed so far, Netten and Germain (2012) presented the Neurolinguistic Approach (NLA) as a tool to complement teachers' methodologies and the second or foreign language teaching and learning. According to the authors, NLA has its focus on the communicative approach and intends to develop the implicit competence and the explicit knowledge. Netten and Germain (2012, p.92) stated that the explicit knowledge is the conscious knowledge of the individual about vocabulary, grammar rules, and other language aspects found in a text. According to them, this is the knowledge taught by the teacher and is accessed consciously by the learner when writing on the second or foreign language or even during the auto-correction of their own mistakes. The authors called the explicit knowledge as *external grammar*. Moreover, implicit competence is the non-conscious ability to use vocabulary and structures of the language in authentic communication composed of pathways or neural connections (Netten & Germain, 2012, p.92). This knowledge is not consciously learned and the learner does not notice he/she is acquiring or learning this ability. Netten and Germain (2012) called this as *internal grammar*.

Netten and Germain (2012) established five topics that teachers may apply to their methodologies in order to better develop the internal grammar. The topics are (a) creation of implicit competence, (b) primacy of oral development, (c) focus on meaning rather than form, (d) authenticity of language and communication situations and (e) interaction between students in the classroom (Netten & Germain, 2012, p.93). In other words, it means that is important for teachers (a) plan and develop methods to explain the language rules in a way that students could be guided on the connections that they will create to develop the internal grammar. (b) To establish situations in which students can develop communications more than do simple exercises, like fill the gaps or text translation. (c) To teach students based on the message wanted to be understood. It is important for the teacher to explain grammar in his/her classroom, however, more important is for the teacher to be aware that students do not have to know terminologies or how to explain that rules, students have to know how to apply that. Furthermore, (d) – complementing the aspect (b) – emphasize the importance of stablishing situations of real use of language. Although it was previously mentioned that role-play activities are helpful to the development of pronunciation and fluency on the second or foreign language, in more advanced groups it may be not so useful. Yet, (e) should be a result of the (d) – authenticity of language and communication situations. During the establishment of real communicative situations, it is important for teacher to plan activities in which students will interact among them.

Nevertheless, the NLA is a very recent methodological propose and needs more studies to analyze its functionality and effectiveness on second or foreign language teaching and learning. The results achieved were developed in few classes and for a considerable but small group of students, and most of the success was empirically observed; only a few analyses were based on brain changes and formal evaluation of the comparisons between, before and after levels of fluency and success on the second or foreign language.

To end up, in order to summarize the main contributions of neuroscience studies to be taken into consideration in the foreign language teaching and learning methodologies which could be applied in classrooms, it is presented a summary table (Table 4). The aspects present on the table were classified according to each author research and contain the most relevant findings and conclusions by the authors mentioned in this section.

Table 4 – Neuroscience contributions to the foreign language teaching and learning methods

<i>Author(s)</i>	<i>Contribution for supporting foreign language teaching and learning methods</i>
Munakata, Casey and Diamond (2004)	<ul style="list-style-type: none"> <li>- Genetic influences on the capacity to learn new languages;</li> <li>- Behavioral tasks (activities in which students participate actively) respond better in children and adolescents;</li> <li>- Less developed brains have easiness on learning and acquiring an L2 (critical and sensitive period hypothesis);</li> <li>- Private or small groups are more efficient to language learning (teachers are able to focus on students individuality);</li> <li>- Cognition, perception, and emotions are connected to language learning (comfortable, relaxed and less authoritarian environments provide better learning conditions).</li> </ul>
Nergis (2011)	<ul style="list-style-type: none"> <li>- The teaching and learning methodology of L2 should be similar to those applied to the teaching and learning of L1;</li> <li>- L2 should be taught in a practical way, following the order communication-grammar;</li> </ul>

	<ul style="list-style-type: none"> <li>- To try to communicate to students using the L2, starting from simple dialogues and improving it over the time;</li> <li>- Metalinguistic is very important. Formal education is essential to a better development of it (teachers help students to be conscious about their own mistakes).</li> </ul>
Kuhl (2011)	<ul style="list-style-type: none"> <li>- Social interactions in order to provide implicit inputs, naturalizing the new language;</li> <li>- Sufficient exposure to language to develop fluency in it;</li> <li>- In children, identify with whom the child is going to speak in each language;</li> <li>- The earlier the second language acquisition and learning is started, the easier it will be to improve language in the future;</li> <li>- To put students in contact with the new language: listening and speaking activities or role-play activities, for instance;</li> <li>- Reflexive activities require more brain effort and turn the new language more significant;</li> <li>- Also remains the importance of teaching language in a social way;</li> <li>- To speak with students in the second language, even simple dialogues.</li> </ul>
Netten and Germain (2012)	<ul style="list-style-type: none"> <li>- Neurolinguistic Approach (NLA);</li> <li>- To help students on the development of the language network (connections between implicit and explicit knowledge);</li> <li>- Primacy of oral development, firstly than other activities;</li> <li>- To focus on meaning instead of form (grammar in use);</li> <li>- Social practice of the L2/Interaction with other people who speaks the L2 or among students in the classroom.</li> </ul>
Guy and Byrne (2013)	<ul style="list-style-type: none"> <li>- Stimulation of working memory by tasks that focus on only one objective;</li> <li>- To relate new knowledge with previous one, establishing a network of the topics of the class (concept maps);</li> <li>- To apply default tasks aiming students autonomy to build the knowledge network;</li> <li>- To work in groups, in order that students are able to share different knowledge and experiences about the L2.</li> </ul>
Alonso (2017)	<ul style="list-style-type: none"> <li>- Social interaction is crucial to turn the short-term memory into long-term memory (by the social interactions, brain classifies what is important or not);</li> <li>- The quantity of inputs and its quality are determinant to L2 success;</li> <li>- To establish communications on the L2 during the classroom;</li> <li>- To put students in contact with the L2 in different moments outside the class period;</li> <li>- Formal education contributes to L2 success and fluency;</li> <li>- Reading ability is not natural. It can be taught by phonological aspects or visual recognition of words;</li> <li>- Teacher should experiment different approaches in order to know characteristics of their groups to develop further classes;</li> <li>- To believe in students ability to learn, supporting them to achieve their objectives in the language learning;</li> <li>- To develop a comfortable learning environment;</li> <li>- Sufficient sleep hours (6-8 hours a day) are crucial for brain to select and store information;</li> <li>- To stimulate students self-control and ability to focus on their objectives;</li> <li>- Self-evaluation of teachers' methodologies;</li> </ul>

- |  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|--|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  | <ul style="list-style-type: none"> <li>- Activities should be planned to progressively increase the level of difficulty;</li> <li>- Activities should involve different sensorial areas (listening, speaking, reading...);</li> <li>- Learning language early will help students to have easiness on it;</li> <li>- Younger learners move faster among different language patterns, older learners move slowly;</li> <li>- Motivation is crucial to L2 learning (by motivation brain develops interest and desire);</li> <li>- Teachers should monitor and interfere on student's interlanguage.</li> </ul> |
|--|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

*Source:* Created by the author using as a basis Guy and Alonso (2017); Byrne (2013); Kuhl (2011); Munakata, Kasey, and Diamond (2004); Nergis (2011); Netten and Germain (2012).

By the analysis of Table 4, it is seen relevant contributions of the neuroscience studies on the support of second or foreign language teaching and learning, as well it is noticeable some similarities proposed by the authors in their conclusions. Nevertheless, the relation between neuroscience and education, called neurocognition by some authors, needs deeper analyses and further studies, in order to get results that are more precise; although, there are strong evidence proving the hypothesis presented in this section, and it surely can help in some manner second or foreign language teachers' methods.

### Final considerations

Neuroscience has, so far, dedicated a lot of attention on brain functionality and development. In the language field, it has established many discoveries in which it could help our understanding of how language works in our brain.

The objective of this research was to establish manners in which neuroscience may contribute to language teaching and learning methods, in order to facilitate teachers works as well as to improve the effectiveness and quality of learning, using neuroscience as a support for teachers' methodologies. Moreover, the research connecting neuroscience to education are very recent and some authors used the term 'neuroeducation' to classify this field of research.

Analyzing the material found about the topic it was found that the primordial factor to connect neuroscience and education is the studies dedicated on brain functionality and which areas are activated to each language characteristics. By knowing brain areas activated for language, the authors who dedicated their studies on neuroeducation analyzed what attitudes activate a specific area and how it can be stimulated in a classroom.

Although neuroeducation contributions, it needs deeper analyses and further experiments and discussions to reach the point of being able to be specifically applied to develop or improve methodologies to work with L1 and L2. It is essential for the future of this field that more teachers start to study neuroscience research, as well as to find new methods to take it to the language classroom.

Nevertheless, it is important to mention that neuroscience has many different limitations on the educational field. Lief (2014) stated that neuroscience does not have complete data about how it really works on education. Also, there are a lot of misunderstandings about neuroscience discoveries and a popular belief that it can dramatically change educational patterns<sup>8</sup>. According to the author, there are many more

discoveries that are unknown than what is known so far and teachers should be aware of the abyss between theory and practice. Lief (2014) affirms that teachers may try to apply neuroscience to classroom methodologies, however, it is important to be cautious and analyze if it is providing any change and improvement in the result of the learning process, based on students' response, ability and easiness on the use of L2.

Finally, we understand that although Applied Neuroscience is still a young field, it is important to include it as part of the program of second language or foreign language teacher's plan of capacitation, since the undergraduate level, in order to enable teachers to further use it in the educational environment. Knowing neuroscience is essential to better understand how students' brains work and how we can contribute to its functionality in order to facilitate the language learning and improve the effectiveness of our teaching techniques.

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## Notes

(1) The term *canonical* is used to refer to things that are ordered; in this case, refers to the sentences that follow the same word order, even in different contexts.

(2) Fiber pathways are responsible to connect different brain areas in the same hemisphere. They could be short fiber pathways, the ones that connect areas or structures near among each other, and long fiber pathways, the ones responsible to connect distant areas.

(3) Density of synaptic is responsible for neural connections.

(4) Axon myelination is responsible for the agility of information between neural connections, however, if more is the myelination, then less is the capacity of processes different information at the same time.

(5) Bottom up process begins from the sensory inputs to the final comprehension. In other words, first the individual receives the information, analyze this and so give meaning to the information.

(6) Different from the bottom-up process, the top-down process first apply meaning to the information and so analyze it.

(7) Dopamine is one of the hormones responsible for the learning capacity.

(8) For further discussion about the misunderstandings of neuroscience in the educational field, it is suggested the book *Brain Waves Module 2 – The Royal Society* (2011), as well as Lief (2014), and Walker (2015).