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The effects of Bilingualism on brain functions: What recent studies have to say

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Trabalho de Conclusão de Curso
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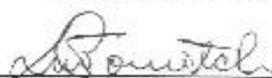
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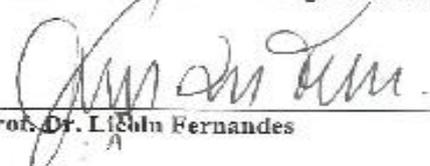
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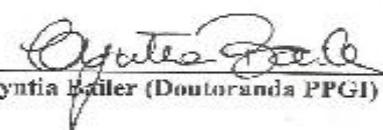
Trabalho de Conclusão de Curso (TCC) para a disciplina LLE7462 do Departamento de Língua e Literatura Estrangeira do Centro de Comunicação e Expressão da Universidade Federal de Santa Catarina – Curso de Letras – Língua Inglesa e Literaturas, como requisito parcial para obtenção do título de Bacharel em Letras – Língua Inglesa e Literaturas.

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ABSTRACT**The effects of Bilingualism on brain functions: What recent studies have to say****Cristina da Silva Ferreira****Universidade Federal de Santa Catarina
2015****Prof. Dr. Lêda Maria Braga Tomitch**

This study is a review of the recent scientific literature that aims to answer the research question: “What are the effects of bilingualism in terms of brain function?”. The new technologies that obtain brain data allow researchers to identify the areas of the brain that are active during language processes such as reading, speaking, translating and also switching between languages when the process concerns a bilingual brain. With the use of neuroimaging tools, researchers have found intriguing results about the brain concerning other brain functions with respect to bilingualism and acquisition of a second language. This study seeks for the most relevant information in this area with respect to age of acquisition, child development, aging, preventions against brain damage, among other factors. The neuroimaging has provided researchers to check on delay on onset symptoms of Alzheimer’s disease, increase in the plasticity of matters (Grey-matter and White-matter) of the brain as well as children outperforming concerning reading and speaking tasks.

Key-words: bilingualism, brain functions, neuroimaging, executive control.**Number of words:** 6.134**Number of pages:** 22

RESUMO

The effects of Bilingualism on brain functions: What recent studies have to say

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**Universidade Federal de Santa Catarina
2015**

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Este estudo é uma revisão da literatura científica recente que visa responder a pergunta de pesquisa: "Quais são os efeitos do bilingüismo em termos de funcionamento do cérebro?". As novas tecnologias que obtêm os dados cerebrais permitem aos pesquisadores identificar as áreas do cérebro que se põe ativas durante os processos de linguagem, tais como leitura, fala, tradução e também enquanto o cérebro alterna entre idiomas quando o processo diz respeito a um cérebro bilíngüe. Com o uso da ferramenta de neuroimagem, os pesquisadores descobriram resultados intrigantes sobre o cérebro em relação a outras funções cerebrais quando se trata de bilinguismo e aquisição de uma segunda língua. Este estudo se propõe à buscar as informações mais relevantes nesta área em relação à idade de aquisição, desenvolvimento infantil, avanço na idade, prevenções contra danos cerebrais, entre outros fatores. A neuroimagem forneceu aos pesquisadores verificar atraso no início dos sintomas da doença de Alzheimer, aumento da plasticidade das massas cinzentas e substância branca (ou massa branca) do cérebro, bem como crianças bilingues superando seus colegas monolingues no que diz respeito à tarefas de leitura e fala.

Palavras-chave: Bilinguismo, funções do cérebro, neuroimagem, controle executivo.

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References.

1. Introduction

Since the innovation of technologies such as neuroimaging, which emerged in the mid-90's, a lot has been said about Bilingualism. A considerable amount of researchers have been investigating the effects of this phenomenon in the brain since then. Such effects embrace, for example, issues related to child development, advantages towards aging and preventive damage in cognitive functions (Bialystok, 2012), to mention a few.

Before neuroimaging entered the scene of these studies, many other research procedures to study the monolingual and the bilingual brain were used, many of them coming from the area of neuropsychological and neurocognitive studies. Different tools were applied to analyze behavioral data coming from instruments such as questionnaires, image connections as the Stroop task (See figures 3 and 4 in section 5) and language tasks, among others.

With the advent of neuroimaging, findings regarding the implementation of language processes in the brain have significantly boosted in the sense that researchers can be more precise in relation to the assumptions made. The neuroimaging tool actually enables one to see the brain in action, with relevant activity in specific brain areas being traced to the cognitive task being carried out. In fact, researchers use the same behavioral tools as they used to before, but now they use them together with the support of a neuroimaging tool such as fMRI (Functional Magnetic Resonance Imaging) (Tomitch, personal communication).

Studies have recently found that the structure of the brain changes with the experience of learning a second language (Michelli, Crinion, Noppeney, Doherty, Ashburner, Frackowiak, Price, 2004). Actually, previous research had already signaled that there are factors in learning in general that shape the brain, but more recent studies include second language acquisition as part of this set of factors. According to the researchers mentioned above, the hypothesis before the event of FMRI that maybe there would be a genetic

predisposition for such change is now contested throughout studies that have investigated early bilinguals who learned through experiences in life, such as family conditions and immigration situations.

The combination of passion for teaching English as an L2 and the curiosity in relation to the benefits in real life experiments in the bilingual field have given me the motivation to read and research such authors as Ellen Bialystok, Gigi Luk, among others.

Based on the above, the objective of this study is to search for information on the effects of bilingualism in the brain. Recent studies seem to indicate that acquiring a second language, early or later in life, can benefit the brain in many aspects.

Thus, the present study seeks to answer the following research question:

- a) What are the effects of bilingualism in terms of other brain functions?

I intend to answer the former question by showing studies made by researchers and authors from the brain and bilingualism area, with the focus on brain functions and its benefits, taking into consideration that this study has the propose of having a positive approach of learning a second language independent from the age of acquisition.

1.1. Significance of the study

Evidence will be sought in terms of what are the effects of bilingualism in terms of other brain functions, such as aging, structural changes and possible benefits of learning a second language other than the benefits of the language itself, in order to have a review of the recent scientific literature. This review might assist the area of EFL (English Foreign Language), both teachers and learners, having the focus on the latest findings about this subject. This way, the professionals of this specific area will be able to understand more about the subject bilingualism and brain functions and possibly feel more motivated to teach

an L2 as well as motivate their own students to persevere in their learning of the L2, since there is scientific evidence for its possible benefits.

1.2. Organization of the study

This study is organized into eight sections. In the first section, I present the introduction to the theme and I also describe the significance of the study and the organization of this paper. In the second section, I offer readers the method used to select the material such as articles, books and other readings. In the third section, I give them an explanation about the brain and the most relevant areas for the language processes. As well, in the fourth section, definitions of the term bilingualism provided by some of the authors cited along this study are presented. In the fifth and sixth sections, the brain studies and behavioral studies selected for this review are described along with the relevant results and conclusions brought by the authors in relation to the main objective posed in this study. In the seventh section, I present some of the probable benefits of bilingualism other than those of learning the language itself. And finally, in the eighth section, I conclude this review by giving an overall vision of the facts revised in this study.

2. Method: Selection of materials

This study is a short piece of bibliographical research which tries to provide a synthesis of recent studies in terms of the relationship between bilingualism and brain function. It aims at reviewing articles from *Periódicos CAPES* (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) database in this area and a smaller number of articles from the source SCIELO (Scientific Electronic Library Online) from the last fifteen

years or so, trying to gather information on the effects of this phenomenon concerning brain function.

Firstly, two key words were selected to find the articles in both databases to start off the research of the study: ‘Bilingualism’ and ‘brain functions’. More than a hundred articles emerged and then the first twenty articles that had the tendency to be the more specific ones were selected to be read, because they had the terms searched in their abstracts. In the first proposed process of reading, some of the articles were discharged for irrelevance. Irrelevance here means that the articles did not have the clear set of information that this study sought or they talked about the same subject in the same sense or studies already posted in other former studies. Some of them had the key words but did not have the results of the experiments, only the methodical tools. Going back to the list, the replacement of these discharged articles was made following the list of CAPES using the two terms. At the end, because of time and space restrictions, and also based on strict relevance to the objective of this study, sixteen articles from CAPES were selected and read for this study. One article from SCIELO was used on the section “*Defining terms*”. It is important to mention that during the process of reading, other articles and readings were used to corroborate and discuss the views of these studies as well.

The articles were used in this study for gathering information about conceptualization, contextualization and main findings in relation to the research question posed, following the chosen category of analyses: main findings on the effects of bilingualism on brain functions. Therefore, these articles were read seeking for evidence on the theme and also aiming to raise the most important findings posed by the authors.

The intention was to have a review of literature that would provide information about bilingualism and brain functions after the advent of the FMRI or other neuroimaging tools.

3. The Brain

According to Gellatly and Zarate (1999), the human brain is an organ that weighs around 1.4 kilos and has two hemispheres, the left hemisphere and the right hemisphere. These two hemispheres are divided into several parts such as the sub-cortical parts and the cerebellum. The brain is also divided into two types of matters, the grey-matter, which is the external part of the organ, and the white-matter, which is the internal part.

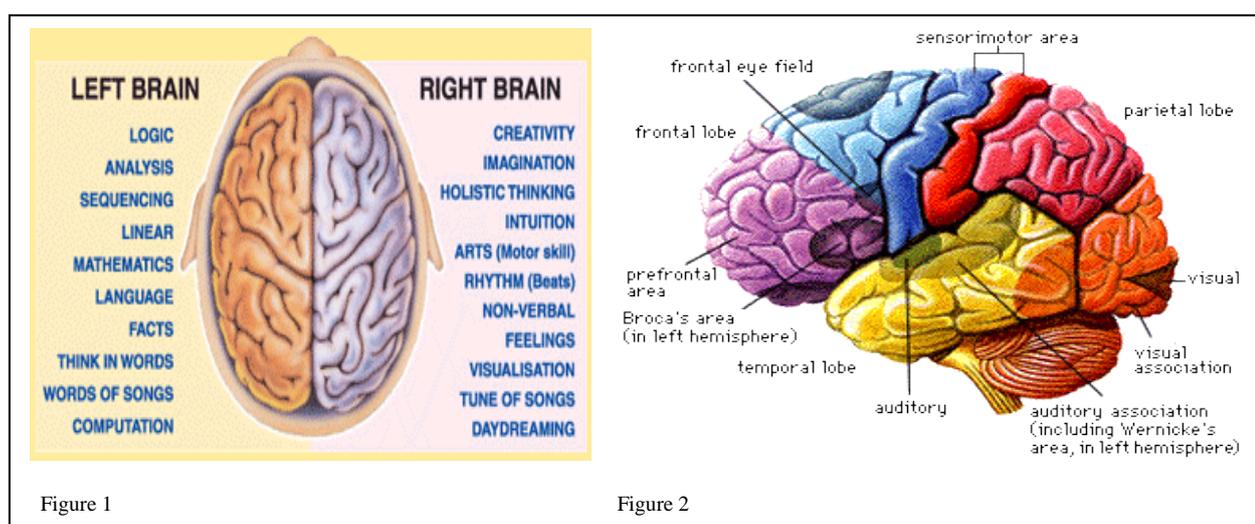


Figure 1

Figure 2

Figure 1: Left/Right brain. Source: <http://ucmas.ca/our-programs/whole-brain-development/left-brain-vs-right-brain/>

Figure 2: Areas of the brain. Source: <https://www.willamette.edu/~gorr/classes/cs449/brain.html>

Figure 1 shows the brain divided into left hemisphere and right hemisphere with a brief description of the functions each hemisphere is able to deal with. It is possible to identify by the image that the left hemisphere is the more logical and factual side of the brain while the right hemisphere, more intuitive and, not so straightforward functions. Figure 2 shows more specific areas and regions of the brain, also showing the areas usually known to be connected with language.

As put by Gellatly and Zarate (1999), years ago, by 322 B.C., the assumption made by well-known philosophers such as Aristotle, and some physicians, was that, since the touch of

the brain did not cause any sensation, the set of sensations must come from the heart. Galen (199 A.C.), a Greek physician, assumed, using animal dissection, that the brain was the organ responsible for the sensations and voluntary movements throughout the body (Gellatly & Zarate, 1999).

Since then, the brain has been investigated by research groups of different areas such as medicine, science, philosophy, genetics, surgery, neuropsychology and many others, in order to identify processes and unveil the mysteries of this organ.

As observed by Tomitch (2013), the most known areas connected with language processing are Broca's and Wernicke's. The names of the areas were given in honor to the physicians who were able to find out about the link between language processing and the brain. Paul Broca was born in 1824, and was a French neurologist and anthropologist whose investigations with the tools that were available at the time (1861), discovered a specific type of aphasia, which is a speech disorder that is related to a specific brain region (the left inferior frontal lobe – Broca's area). In this specific type of disorder, the individual is able to understand what is said but he/she has difficulties with the reproduction of the speech.

Carl Wernicke was born in 1848, and was a German anatomist, psychiatrist and neuropathologist. He also discovered a different type of aphasia in the year of 1874. In this case, the individual speaks fluently but most of what is said does not make sense. Wernicke related this aphasia to the left posterior superior temporal region (Wernicke's area). Both areas, Broca's and Wernicke's, have connections with reading processes.

The discovery of these two aphasias made by these two important figures opened a vast field of other discoveries on the brain and its functions that have been investigated for years until the recent days. Most of the disorders names caused in the brain start with the prefixes "a" (meaning without) or "dys" (meaning "bad"), but what is important here is to acknowledge that both of the nominations can be connected with cognitive reserve and

executive control, which is, simply speaking, among other functions, the ability to manage the languages and situations of conflict and problem resolution.

There are many types of brain cognitive decline, being Alzheimer's disease, the most common among them. This disease is classically defined as a dual clinicopathological entity (Dubois, 2010) and it is one of the diseases discussed in this study as one of the aspects related to brain activity, executive control and cognitive reserve.

The brain is one of the most complex organs in the body and it works as a muscle, thus it is possible to be extended and exercised. According to Michelli (2004, p. 757), there are growing evidences that the brain structurally changes in relation to environmental demands as learning facts. Studies show that there are differences in structure related to plasticity and GM (grey-matter) and WM (white-matter) density.

In this sense, the proposed study will review the literature based also on the changes that this organ is able to accomplish with the acquisition of a second language as well as the changes in brain functions concerning executive control and cognitive reserve.

4. Defining Bilingualism

In order to understand the benefits and effects of bilingualism cited by the researchers in this review, it is important to try to clarify what it is to be bilingual before trying to bring evidence on how bilingualism relates to brain functions in what concerns aging, development and prevention of damage to the brain systems. This section aims at clarifying this idea using concepts from the authors reviewed in this study and who have tried to define what it is bilingualism.

Bilinguals make up a significant part of the population nowadays (Bialystok, Craig & Luk 2012). Generally speaking, the literature in the area tells us that the phenomenon of

bilingualism can be defined as the ability of an individual to switch between two languages depending on the context or his/her necessities or yet a specific language configuration that subserves the same purpose (Rottava, 2002; Grosjean, 1995). Furthermore, according to Romaine (1995), bilingualism is a resource to be cultivated and not a problem to be eliminated.

According to Bialystok (2010), when it concerns bilingualism, usually the individuals who have this characteristic did not desire for this condition. They were exposed to natural experiences of different language environments, most of the times in early ages. As claimed by Bialystok (2012, p. 240), “Bilinguals are not typically selected for talent or interest. The circumstances of their families, place of birth, or immigration history simply required that they learn more than one language.”

Still, it is important to highlight that, in the groups of bilingual individuals that take part in the studies reviewed in this paper, there are different levels of bilinguals such as the ones who are able to read, write, communicate and understand in a L2 situation as opposed to the ones who are proficient in only one of these skills (Costa & Gallés, 2014).

The literature also brings a type of bilingualism called ‘bimodal’ where individuals use English, or any other verbal language, as well as a Sign language, simultaneously. A group of bimodal bilinguals were part of one of the studies here reviewed (Emmorey, Borinstein, Tompson & Gollan, 2008) and were considered able to articulate and have changes in the brain as the other types of bilinguals. Different from the other types of bilinguals mentioned here who have to make a choice when using languages, these individuals can engage in the use of the spoken and signed word or phrase at the same time (Emmorey et al, 2008).

In another study in the field, Athanasopoulos (2010) analyzed 20 individuals who were Greek living in the UK. These individuals were divided into two groups: more than 10

years living in the UK and less than 10 years living in the UK. As it is possible to see, for this specific study, the only matter taken into consideration was time living in the country where the L2 was spoken, so individuals in this case, as revealed by the researchers, were considered bilinguals for timing experience and not for proficiency.

Overall, to highlight these concepts, there is no evidence in the literature of a person who is 100% bilingual or 100% monolingual. Even monolingual individuals have had some bilingual experience as some school subject or travel necessity, whereas bilinguals have preferences for one of their languages due to the context in which they are inserted in (Bialystok, 2012).

What the literature shows so far is that the typical brain of a bilingual person is not “special” and does not have a specific area or region to accommodate the languages this individual deals with (Gómez, 2010). According to Gómez, the cognitive functions of the cerebral hemispheres are the same in monolingual and bilingual individuals. What there is to believe is that, when a task is proposed, the existing structure, muscles, joints, neuros and regions work together to accomplish the given task. Therefore, the more a task and experience is repeated, the more the final result will be better.

5. Behavioral studies of cognitive processing in bilingual research

According to Kroll (2005), who used the Stroop task (see figures 3 and 4 below) in order to examine lexical choices and word recognition systems in monolingual and bilingual individuals, the variables are different when considering different tasks, but still, a bilingual brain has the same reaction as a monolingual brain, having the same articulation to alternate between one language and another given a determined task.

The individuals analyzed in most of the studies reviewed by Kroll do not have the same level of bilingualism. They were Dutch speakers and Dutch-English bilinguals,

although, some of them could only read in the language proposed and some others could speak and read. The aim of the research was word recognition, so for all the effects, reading in a second language was enough for this task.

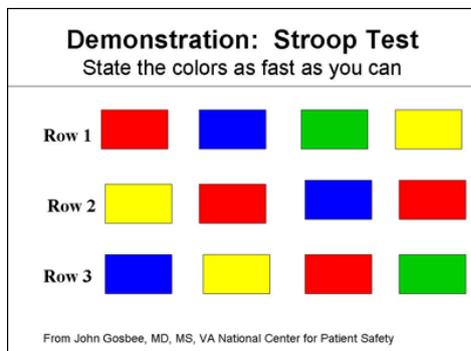


Image 3: Source: <http://www.tomartist.com/2012/12/04/counter-productive-effects-of-multitasking-running-vs-learning-2/>



Image 4:

Source://www.exo.net/~pauld/activities/perception/stroopeffect/stroop.htm

It was once thought by scholars that the effects of bilingualism would be negative, that confusion would be a fact in learning two languages. In that sense, Peal and Lambert (1962, as cited in Bialystok, 2012) made a study with bilingual French and English children and monolingual French children, expecting to reaffirm the negative hypothesis. What was surprising was that the bilingual children had superior performance in most of the tasks, especially in recognition and symbol manipulation (Bialystok, 2012). These results are corroborated in the literature showing that bilinguals are able to control their two languages with relatively high accuracy (Kroll & Sumutka, 2005).

Furthermore, other studies in the same line of research were carried out to replicate this advantage and the results were also positive for bilinguals with respect to their ability to solve linguistic problems and recognition of forms and meanings, as presented below. Weikum (2007) performed a video task with the narrator on the monitor changing languages (French x English), after a period of habituation, to 8 months old children. The aim was to identify which group of children would regain attention to the video when the narrator

changed languages. The results were that the bilingual children showed renewed attention by looking back at the video but not the monolingual children.

Stocco (2014) also brings evidence showing that children raised in bilingual families show superior performance in non-linguistic tasks. It is important to mention that Stocco advocates for the idea that the experience of managing two or more than two languages may “train the brain” and that this training can help to improve cognitive functioning. For Stocco, “executive functions are the mechanisms that enable human cognition to move away from automatic responses, towards more complex, goal-driven behaviors” (p. 51).

According to Bialystok (2011), the brain and the mental functions are to last more if there is an activity to keep them involved. When taking into consideration people who were more than 70 years old and presenting signs of dementia or Alzheimer’s disease, Bialystok found that bilingual individuals around this age noticed the signs of the damage later than monolingual individuals. The author explains that these results are probably due to the executive control of language processing; that is, bilinguals constantly have to deal with candidates from both L1 and L2, which is a configuration that monolingual individuals do not present.

To make clear what is meant by executive control, Miyake et al., (2000, p. 241) defines it as:

A set of cognitive skills based on limited cognitive resources for such functions as inhibition, switching attention and working memory. The neuronal networks responsible for executive control are centered in the frontal lobes, with connections to other brain areas when necessary for specific tasks. Executive control system is recruited into linguistic processing, a configuration not found for monolinguals. The executive control system is well known to be involved in situations where selection or conflict resolution is required.

Years before the assumptions made about the decline of the cognitive system, Folstein, Folstein and Mc Hugh (1975, as cited in Bialystok, 2010), developed a study involving two groups of bilingual and monolingual individuals and they found out that the groups were equivalent in most of the measures except education. In that study, almost two decades before the invention of the new brain reading technologies, the results were 4.1 years of difference when the symptoms of dementia and the Alzheimer's disease onset were detected.

Advantages are also shown in a study carried out by Hilchey and Klein (2011) that found evidence for the contention that bilingualism protects against cognitive decline in older age. Bialystok, Craig and Freeman (2007) studied a set of patients in a hospital records, and the results showed that the bilingual individuals had found the signs of dementia 3-4 years later than monolingual individuals. The results were the following: 75.4 years for monolingual individuals to identify the symptoms of any dementia signs and 78.6 years to identify the same symptoms in bilingual individuals. Years later, a replication study was also done to verify the variables set before in patients with symptoms of probable Alzheimer's disease, and the results remained the same (Craig, 2010).

The studies above showed a very significant delay in the symptoms of Alzheimer's disease or dementia over the years, which may lead to the conclusion that maybe the reason for this delay is that the brain of a bilingual person has more efficient cognitive reserve. It is important to mention here that the researchers were careful enough to analyze individuals with the same lifestyle factors in each study made. Therefore, the difference between them would probably be only the bilingual condition.

In the same line of thought, there are findings in the literature showing that bilingualism can influence not only executive control, but also cognitive reserve. Executive control and cognitive reserve are connected by the same principle: preventing from dementia.

To start discussing the effects of bilingualism on cognitive reserve, it is important to define such theme. Bialystok (2012, p. 246) says that: “Cognitive reserve is the idea that engagement in stimulating physical or mental activity can act to maintain cognitive functioning in healthy aging and postpone the onset of symptoms in those suffering from dementia.”

Furthermore, Costa (2014) also defines cognitive reserve by saying that:

The term refers to the resistance of certain aspects of cognition to brain damage. For example, neurodegenerative diseases can affect the cognitive abilities of different individuals to varying degrees, suggesting that the cognitive abilities of some individuals are more resistant to brain damage (p. 337).

Stern (2002) claims that lifelong bilingualism protects against age-related cognitive decline and that fact meets Costa’s (2014) idea, who claims that cognitive reserve is related to factors such as lifestyle and education. Both agree that bilingualism can be one of the environmental factors that are able to help building brain reserve.

As advocated by Bialystok (2011), the constant use of two languages by bilinguals engages the idea of changes in executive control and stronger cognitive reserve, even on tasks that are completely non-verbal. Bilingualism has the effect of pressuring the executive control to manage attention to a target language, this is the mental activity that makes possible the better executive control and cognitive reserve in bilingual brains.

6. Brain studies in bilingual research

In a compelling fMRI study by Green, Luk, Abutalebi and Grady (2010), analyzed by Bialystok (2011), evidence was brought that bilinguals have the ability to complete tests faster than monolingual individuals. Even with their two languages shifting working, there

was no confusion that made them to be slower than monolingual individuals. This study is a gathering of 10 studies made with children in their early ages as well as adults with signs of dementia in the latest ages.

According to Athanasopoulos (2010), empirical investigations showed that the learning of another language may alter the pre-existing cognitive representations and that bilingual cognition is affected by the length of cultural immersion in the second language country, the language proficiency of individuals, among other factors. The evidence of a study made by this author and his colleagues showed that the restructuring of core components of perception may happen in bilinguals because of the time spent in the L2 speaking country.

Kroll (2005) claims that when bilinguals read words in one of their two languages, information on phonology, orthography and meanings in the other language are activated and that the effects of L1 on L2 are greater than those of L2 on L1. Having in mind the studies presented above, bilingualism would be of interest not only for its own good learning effect, but for the benefits to cognition it provides in general. Bilinguals have the same speed in recognizing words as the monolinguals still with their two languages activated and it is possible for bilingual individuals to recognize words and objects with the same accuracy that monolinguals do, although monolingual individuals do not deal with competition in their brains.

Leonard, Torres, Travis, Brown, Hagler, Dale, Elman and Halgren (2011) carried out a study using questionnaires and the Stroop task to identify how language proficiency can affect the recruitment of classical and non-classical language areas during word processing. The participants here were Native Spanish speakers who had become proficient in the English language. The study took place in the state of California where the Spanish speakers become bilingual early in life when they enter school. The tests used in the Leonard et al's

study were simple but the aim was to identify similarities on the language processes in the brain while reading words in one of their two languages. In the first stage of the research, they claim to have noticed activity in different regions of the brain during the word processes, making it possible to accept the objective of the study, which was to identify recruitment of languages, in other words, to check if it is possible to link the classical and the non-classical languages when one of them is being used in the process of word reading or pronunciation. The authors found that proficiency accounts for neural recruitment differences that happen between languages when they are in use. That means that there are more areas involved in word processing than it was once thought before, as it has been investigated lately.

In a voxel-based morphometry¹ study made by Michelli (2004), it is shown that grey-matter density was greater in bilinguals than monolinguals despite the age of acquisition and level of bilingualism. This study and this exam were made in order to show that the organization in the brain is also due to second language acquisition among other biological factors. The authors showed that the structural organization in bilinguals is related to the use of their second language. According to Michelli, “Learning a second language increases the density of grey-matter in the left inferior parietal and the degree of structural reorganization in this region is modulated by proficiency and the age of acquisition” (p. 1).

Michelli made a study using advanced techniques (voxel- based morphometry - VBM) to investigate healthy right-handed bilinguals in English and Italian and Italian monolinguals in terms of structural changes in the brain due to the acquisition of a second language. During their investigation, the researchers found that there are structural plasticity changes in the brain with the acquisition of a second language. It actually affects the grey-matter in the left hemisphere and there is evidence of this effect also in the right hemisphere. With fMRI scans, it was possible to show that the area that is activated during oral tasks, was

¹ Voxel-based morphometry (VBM) is a whole-brain unbiased technique used to investigate plasticity in brain areas. (Michelli 2004).

the area related to second language acquisition which actually is in the inferior parietal region, as claimed by Michelli.

VBM revealed a greater effect of grey-matter change density in bilinguals than in monolinguals, having in mind that plasticity in certain areas happens because of other factors as well, as other learning aspects as alphabetization and math learning. It is also important to mention that in this study participants were divided into early and late bilinguals and the grey-matter density change happened to both types of bilinguals. Michelle advocates that although there may be changes in the brain due to environmental demands, the changes found in his study in terms of brain structure can also be related to language and proficiency (Michelli 2004).

According to García, Pentón, Fernandez, Medina, Dowens and Carreiras (2013, p.496), “when two languages are simultaneously acquired in early life, more graphic-efficient subnetworks are developed in order to accommodate extra language demands”. Furthermore, the authors say that acquiring a second language early in life can activate brain plasticity, another evidence that the brain changes when there is a demand for a bilingual situation.

Another point to be considered is that “the neural basis of reading in a native language changes when a second language is learnt” (Nosarti, Michelli, Green & Price 2010, p. 315). In this case, Nosarti and colleagues used fMRI with Italian monolingual individuals and Italian/English bilingual individuals and found changes in the dynamic processes of the words in the first language, in this case, the first language being Italian. It is important to observe that bilingualism had an effect concerning brain function and brain structure.

In relation to changes in brain structure, it is valid to go back to the changes in grey-matter density in the study carried out by Costa and Galles (2014), in which the main objective was to define how the bilingual experience sculpts the brain. Changes in the structure of white-matter integrity were reported in older highly proficient

bilingual adults especially in the *corpus callosum* and areas involving verbal fluency tasks. Proficiency in this study was considered by time of acquisition, once participants were 70 years old, on average. (García 2014)

Aging is a concern when it comes to brain activity. The most feared disease of all the brain damages is Alzheimer. The symptoms of Alzheimer's disease are devastating and they act mostly on the cognitive functions and executive control. For bilingual individuals, there seems to be an advantage in this area as well, claimed by Gold, Johnson and Powell (2013): "Aging is associated with neurodegenerative changes that typically lead to cognitive decline. However, there is a great deal in the relationship between cerebral declines and cognitive functioning in aging, with variability in task performance tending to increase with aging" (p. 2841).

García, Pentón, Fernández, Medina, Dowens and Carreiras (2014) used high-resolution structural imaging to access grey-matter volume and also DTI (Diffusion Tensor Imaging²) to access white-matter integrity. The individuals analyzed were lifelong bilingual and monolingual adults. Results indicated that while some adults seem to be more vulnerable to brain decline with diseases such as Alzheimer's, other adults remain cognitively normal. The assumption here is that bilingualism help in the sense of preventing cognitive reserve damage. Their results showed that there was no difference in GM (Grey-matter) volume, but when the white-matter integrity was examined, the results suggested that experiencing lifelong bilingualism can prevent the cognitive reserve to be affected by the decline of the white matter. It is important to mention that, for such study, the cognitive reserve variables that were evaluated included education, intelligence and socioeconomic status. With these three variables, researchers were able to distinguish the ability of the brain to cope with damage, such as Alzheimer's disease and dementia.

² DT MRI is the only non-invasive method for characterizing the microstructural of tissue in vivo. Generating parametric maps that help to visualize different aspects of the tissue microstructure (mean diffusivity, tissue anisotropy and dominant fiber orientation). (Jones & Leemans 2011)

The plasticity of the cognitive system deserves a place in this study as well. According to Bialystok (2011), “the executive control circuits needed to manage attention to the two languages became integrated with the linguistic circuits used for language processing, creating a more efficient network that supports high level of performance” (p. 236). As mentioned by the author, that might explain why bilingual individuals outperform monolingual individuals and also why they better cope and postpone the symptoms of dementia and brain diseases. Hebb (1949), as cited in Bialystok et al, 2011), years before the assumptions made by the authors here cited had begun the path for research saying that “Cells that fire together, wire together” (p. 08)

7. Pondering on the probable benefits of bilingualism

According to Stocco (2014), the biological nature of the benefits of being bilingual is still unexplained. As put by the author, the lack of deeper information about the brain functions concerning bilingualism leaves open a gap for further studies to understand how it progresses and/or the processes are done.

Neuroimaging tools made it possible to see the areas in the brain that are activated during a language task but still the researchers have found blank spaces in their studies to certify their theories concerning anatomical changes and development of the brain in ages of acquisition of the second language.

When the evidence concerns anatomical changes and plasticity, especially when the languages are typically distant in terms of phonology, the documents are scarce or have not been documented so far as a whole (García 2013).

There is still the belief that bilingualism can cause confusion, even delay of some functions and also that bilingualism is one of the causes of aphasia, which is “a disorder due to injuries caused in the brain involving language processing area affecting speech production

or the reading/writing process” (Stocco 2014). However, none of the authors read for this study affirm that bilingualism is a cause for disorders in the linguistic system and none of them affirm that being bilingual increases the life span either. Bilingualism does not prevent any disease from developing, it is supposed that it just delays some of the symptoms.

There is no clear documented evidence for the hypothesis that bilingualism is the cure or a “medicine” for brain disorders, but there is enough evidence to believe in the advantages of the phenomenon and its benefits in a long term period.

8. Final Considerations

The main purpose of this study was to show that, apart from the advantages of the language itself, bilingualism has also the ability to keep the brain healthy and working for a longer period of time.

By reading the literature selected for this review, it was possible to identify an attempt to make bilingualism as an advantage and not as a ‘problem to be solved’ as cited by Rottava (2002) in the beginning of this study. With the help of the new tools such as FMRI, among others, recent findings point to many other advantages of the bilingual brain in terms of brain function, such as the ones discussed in this study: development of brain plasticity, protection of the brain areas, advantages of cognition and reserve, child brain development, protection against dementia and symptoms of Alzheimer’s disease, and increase in the grey-matter.

Before these tools, assumptions were made by the authors and they did not have such technology to see the healthy brain in action when developing tasks in monolingual and bilingual brains. Now, the hypothesis that the acquisition of a second language trains the brain, modifies its structure and preserves its areas against decline with aging seems

plausible. As put by Kroll (2005, p.27), “bilingualism is of interest not only in its own right, but also for the model it provides for cognition in general” (Kroll 2005).

Bilingualism does not have a natural predisposition proved by researchers or scientists, and Gómez (2010, p. 450) states that “to think that to learn to type on a keyboard we would need to grow new fingers on our hands”, meaning that there is no evidence of new brain mechanisms made by bilingualism; it is a matter of better organization and better executive performance (Bialystok, 2011).

The phenomenon is natural, as argued throughout this paper in the literature presented, and the news about it should be spread among L2 teachers and learners, since the benefits of learning a second language are not only in relation to being able to communicate with people from other languages and cultures but also to maintain a healthy brain.

Considering the amount of studies emerged concerning the two key words selected for searching the sources: brain functions and bilingualism, along with the parallel readings found related to the theme, one can speculate that there is still a vast gap to fill in the literature research concerning findings connected with technologies of brain reading. The methodological procedures used by researchers at the present time, including the types of tests and tasks concerning behavioral processes and the technological tools to collect data related to brain processes, leave space for further studies in this area as well.

Bilingualism connected with brain function is an up-to-date and relevant topic to be worked on, not only by researchers in the area, but also by professionals of L1 and L2 such as professors and learners. It should be discussed as a motivating subject at schools and education institutions as a way to improve knowledge and understanding in relation to the possible beneficial effects of acquiring a second language at any stage in life.

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