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The effects of learning foreign languages in different stages of adulthood

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DEPARTAMENT D'ESTUDIS ANGLESOS I ALEMANYS

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Abstract

This thesis aims to examine the effects that learning foreign languages has on the lifespan, with a particular focus on adulthood and its different stages. It begins reviewing multiple areas related to language learning, brain development, structure and function, bilingualism, multilingualism, and some methods to measure changes in the brain. For the purpose of this study, two cognitive scientists were interviewed through Microsoft Teams, and their answers were used in order to prove or disprove the hypothesis. Furthermore, the results not only show the interpretation but also how it applies to the theoretical section. This study exhibits how people in late adulthood can achieve native-like proficiency when learning languages. It also states the importance of awareness of the benefits of learning languages since it would mean the promotion of healthy cognitive aging and the delay of neurological diseases that are common in late adulthood due to a deficit in brain training.

Key Words: Bilingualism, Adulthood, Language Learning, Multilingualism, Neurolinguistics, Cognitive Science

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List of Abbreviations

AoA	Age of Acquisition
CPH	Critical Period Hypothesis
DTI	Diffusion Tensor Imaging
EEG	Electroencephalography
FA	Fractional Anisotropy
fMRI	Functional Magnetic Resonance Imaging
GM	Gray Matter
IPL	Inferior Parietal Lobe
L1	Language 1
L2	Language 2
M1	Primary Motor Cortex
MD	Mean Diffusivity
MEG	Magnetoencephalography
MRI	Magnetic Resonance Imaging
RD	Radial Diffusivity
SMA	Supplementary Motor Area
TMS	Transcranial Magnetic Stimulation
VBM	Voxel-Based Morphometry
WM	White Matter

Glossary

Term	Definition
Angular Gyrus Syndrome	The angular gyrus syndrome is a constellation of neuropsychological deficits found in patients with damage to the dominant angular gyrus and surrounding brain regions. It has been defined as consisting of the following neuropsychological deficits: transcortical sensory aphasia, alexia with agraphia, and components of Gerstmann's syndrome (acalculia, agraphia, difficulty in distinguishing left from right, and finger agnosia).
Aphasia	Loss or impairment of the power to use or comprehend words usually resulting from brain damage (as from a stroke, head injury, or infection)
Axon	A usually long and single nerve-cell process that usually conducts impulses away from the cell body.
Brain Nodes	A predefined collection of brain tissue.
Broca's Aphasia	An aphasia is characterized by impairment of expressive language (speech, writing, signs) and relative preservation of receptive language abilities (i.e., comprehension). This condition is caused by lesions of the motor association cortex in the frontal lobe (Broca's area and adjacent cortical and white matter regions).

Cognitive	(1) of, relating to, being, or involving conscious intellectual activity (such as thinking, reasoning, or remembering).
Developmental Dyslexia	A cognitive disorder characterized by an impaired ability to comprehend written and printed words or phrases despite intact vision. This condition may be developmental or acquired. Developmental dyslexia is marked by reading achievement that falls substantially below that expected given the individual's chronological age, measured intelligence, and age-appropriate education. The disturbance in reading significantly interferes with academic achievement or with activities of daily living that require reading skills.
Diffusion Tensor Imaging	The use of diffusion anisotropy data from diffusion magnetic resonance imaging results to construct images based on the direction of the faster diffusing molecules.
Electroencephalograph	An apparatus for detecting and recording brain waves.
Episodic memory	Long-term memory of a specific event that was personally experienced at a particular time or place in the past
Executive Functions	The group of complex mental processes and cognitive abilities (such as working memory, impulse inhibition, and reasoning) that control the skills (such as organizing tasks, remembering details, managing time, and solving problems) required for goal-directed behavior.

Executive Suite	The group of areas of the brain dedicated to the executive functions.
Fractional Anisotropy	Fractional anisotropy (FA) is a common measurement used in DTI studies and ranges from 0, isotropic movement of water molecules (e.g., cerebrospinal fluid), to 1, anisotropic movement of water molecules (e.g., fiber bundles).
Functional Magnetic Resonance Imaging	Magnetic resonance imaging used to detect physical changes (such as blood flow) in the brain resulting from increased neuronal activity.
Gray Matter	Neural tissue especially of the brain and spinal cord that contains nerve-cell bodies as well as nerve fibers and has a brownish-gray color.
Impairment	The act of impairing something or the state or condition of being impaired**:** diminishment or loss of function or ability.
Input (Brain)	(1e) A stimulus that acts on and is integrated into a bodily system.
Lateralization	Localization of functions refers to the principle that specific functions (language, memory, hearing, etc) have specific locations within the brain.
Lesion	(1) Injury, Harm.
Mean Diffusivity	MD describes the average mobility of water molecules.

Magnetoencephalography	A non-invasive technique that detects and records the magnetic field associated with electrical activity in the brain.
Magnetic Resonance Imaging	A non-invasive diagnostic technique that produces computerized images of internal body tissues and is based on nuclear magnetic resonance of atoms within the body induced by the application of radio waves.
Myelin	A soft white material that forms a thick layer around the axons of some neurons and is composed chiefly of lipids (such as cerebroside and cholesterol), water, and smaller amounts of protein.
Myelination	(1) The process of acquiring a myelin sheath.
Neuroplasticity	The capacity for continuous alteration of the neural pathways and synapses of the living brain and nervous system in response to experience or injury.
Stroke	(5) Sudden impairment or loss of consciousness, sensation, and voluntary motion that is caused by rupture or obstruction (as by a clot) of a blood vessel supplying the brain, and is accompanied by permanent damage of brain tissue.
Trauma	(1) An injury (such as a wound) to living tissue caused by an extrinsic agent.
Transcranial Magnetic Stimulation	A non-invasive technique for stimulating brain neurons that uses an insulated electromagnetic coil placed superficially on the skull to produce magnetic fields

	which penetrate cranial tissue and generate electric currents in specific areas of the brain.
Voxel-Based Morphometry	Voxel-based morphometry is a computational approach to neuroanatomy that measures differences in local concentrations of brain tissue, through a voxel-wise comparison of multiple brain images.
Wernicke's Aphasia	Sensory aphasia in which the affected individual speaks words fluently but without meaningful content
White Matter	Neural tissue especially of the brain and spinal cord that consists largely of myelinated nerve fibers bundled into tracts, has a whitish color and typically underlies the cortical gray matter.

Note. Some definitions have been written by the author considering the background information on this thesis. All the other definitions have been taken from various sources included in the list below. In addition, American English has been used to write this thesis. Therefore, the spelling of certain words may be different from other varieties.

(1)https://www.merriam-webster.com

(2)https://medical-dictionary.thefreedictionary.com

(3)https://www.online-medical-dictionary.org

(4)https://www.sciencedirect.com/topics/neuroscience/angular-gyrus

(5)https://pubmed.ncbi.nlm.nih.gov/24319426/#:~:text=In%20functional%20brain%20networks%20a,vary%20considerably%20in%20the%20literature.

(6)https://www.sciencedirect.com/topics/nursing-and-health-professions/mean-diffusivity

(7)https://www.sciencedirect.com/topics/neuroscience/fractional-anisotropy#:~:text=Dictionary%20of%20Terms-,Fractional%20anisotropy,macromolecules%2C%20cell%20membranes%2C%20etc.

(8)https://www.psychologyhub.co.uk/student-resources/paper-2-biopsychology/brain-localisation-and-hemispheric-lateralisation/

1 Background Information

1.1 Introduction

Learning a foreign language is a demanding task, but what impact does it have on the adult brain? Recent research in the field of neuroscience has provided an insight into the cognitive and neural mechanisms involved in language learning, as well as the benefits that can arise from bilingualism. This bachelor's thesis aims to explore the effects of learning a foreign language on the adult brain, with a particular focus on the neural aspects of learning and adult-onset issues.

The literature on brain plasticity and language acquisition will be examined, exploring how learning a foreign language can shape the structure and function of the brain, and what consequences age-related cognitive decline has on the brain.

By bringing together insights from linguistics, neuroscience, and experienced specialists, an overview of the impact that learning a foreign language can have on the adult brain will follow.

1.2 The adult brain

1.2.1 The development of the Brain

Human brain development is a process that originates in the third gestational week of the prenatal period and prolongs throughout the lifespan (Stiles & Jernigan, 2010). At birth, the brain already contains all the neurons it will have throughout its existence but, until the teenage years, it is continuously growing in volume (Johnson, 2001). Nonetheless, the way the brain develops is by creating and eliminating connections. We cannot consider a brain fully matured until young adulthood (Giedd, 2015). According to the Massachusetts Institute of Technology (*Young Adult Development Project*, n.d.), in young adulthood, the brain undergoes different developmental changes.

Firstly, the brain connections and nerve fibers settle down to a more productive and efficient system. In addition, the connections between different brain parts are also becoming more efficient, and the executive functions are easier to perform because of the development of the "Executive Suite" (the different areas of the brain dealing with the executive functions).

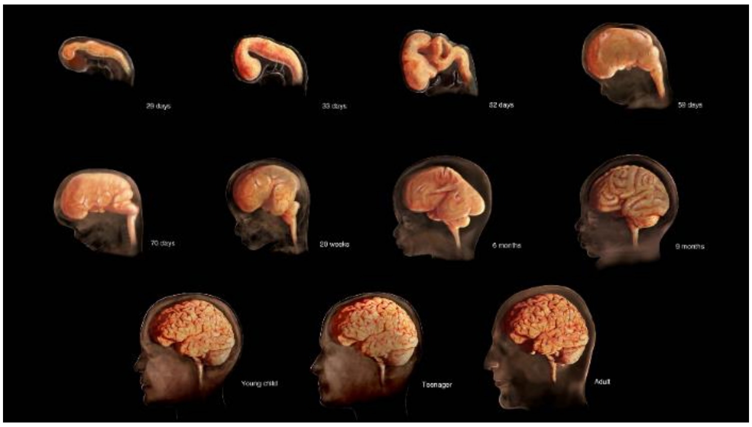
In the adolescent period (from ages 10 to 19 years), some of the brain connections have been already made and it is the perfect time for the brain to start experiencing with adaptability due to all the changes that adolescence has. At this stage of life, the brain is experimenting with external factors such as sociability, sexuality, as well as physical and intellectual changes. Moreover, it is worth adding that hormonal fluctuations have a great impact on various aspects that are present only in adolescence and, therefore, are unique to this moment of one's lifespan rather than being permanent adaptations. This can be illustrated with social attention since it is a key aspect of teenagers to meet social expectations. However, adults do not have the need for such societal prospects (Casey 2013; World Health Organization: WHO, 2019) .

After the teenage period, and between 20 and 25 years of age, the brain is still going through the process of enhancing connections between nerve fibers and brain regions in order to improve the system. However, it is not until the person is in their mid-20s that these connections are almost finished (Giedd, 2015). Therefore, we could argue that then the brain is fully matured by the late 20s.

Once the body is aging certain cognitive abilities decline, these include working memory and speed processing (Peters, 2006). In addition, a decrease in Gray Matter (GM) and White Matter (WM) volume is determined to arise (Farokhian et al., 2017). Moreover, the development of the brain is directly correlated with external stimuli such as visual input or social contact with animate objects (Johnson, 2001). The outer input can have a profound impact on brain development since there are critical periods when the brain is more sensitive to external influences. Therefore, exposure to enriched environments, including opportunities for learning and exploration, can promote brain plasticity and enhance cognitive function (Sale et al., 2014).

Overall, brain development is still a conundrum that requires further research, even though the understanding of it has increased severely in recent years (Zelazo & Lee, 2010).

Figure 1.
A representation of brain development.



(Retrieved from: https://ehp.niehs.nih.gov/doi/10.1289/ehp2268)

1.2.2 Aging and the Brain

As the human body ages, the brain undergoes several changes that are not only physical but also cognitive. However, it is still unclear the rate at which the brain changes since they are not uniform, they "do not occur to the same extent in all brain regions" (Peters, 2006), and there are many environmental factors affecting it. Moreover, researching this area seems as though it is complicated due to the fact that participants would need to be studied for longer periods of time (months or even years). Overall, some things that are known now are that the cortical thickness becomes thinner (Fjell et al., 2015) and white matter volume decreases (Liu et al., 2017).

Peters (2006) also adds that "incidence of stroke, white matter lesions, and dementia also rise with age, as does the level of memory impairment and there are changes in levels of neurotransmitters and hormones” (p.84). This indicates that as the brain ages the deterioration, there are several hormonal and mental changes that arise, including the possibility of brain damage and impairment. In addition, in the normality of aging, there are some fatal consequences that can affect daily life and, in extreme cases, become a clinical issue. According to Bherer et al. (2013) Some of these consequences are mainly related to a cognitive function decrease, these include reductions in mental speed, executive functions, and episodic memory. Moreover, a big amount of the elderly population suffers from a mild impairment due to a cognitive decline in areas including decision-making, attention, perception, reasoning, and intelligence (Baghel et al., 2017).

Even though aging is a common thing that cannot be fully ceased, and the consequences are detrimental, it can be delayed. One of the things that can offset the impacts of aging is physical activity, this is well known to be a crucial aspect of daily life for healthy aging and the prevention of several diseases (Bherer et al., 2013). Furthermore, various studies have found that other behaviors that can promote healthy aging are the following: not smoking, moderate alcohol consumption, maintaining a healthy weight, good hygiene, diet, and education (Peel et al., 2005; Khaw, 1997; Heller & Sorensen, 2013; Batsis et al., 2021)

All in all, there are several adverse effects on aging. Nonetheless, these can be lingered by employing the well-known conducts that lead to what is considered a healthy lifestyle.

1.3 Language in the brain

The study of language and the brain has been a relevant topic in cognitive neuroscience. Numerous studies have identified various brain regions involved in language learning and processing (Price, 2012). Understanding the specific roles of the areas engaged in language processing can provide insights into how the brain enables us to communicate and comprehend language.

Furthermore, the information provided below on the brain areas is subjected to the phenomenon of lateralization. About 95% of people have the regions in the same place, but there is a very small percentage of people who have them somewhere else in the brain. As it is already mentioned, this is called lateralization and it can occur for different reasons. One of them is recovery of a brain lesion, in this case when a brain area is damaged and cannot be recovered the functions it used to do are moved to another area of the brain (see 1.4.1 on Neuroplasticity below for more information).

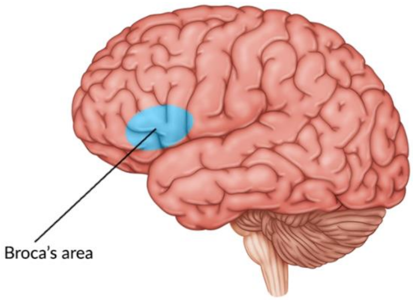
Another reason is left-handedness, it is known that the brain is cross-wired (the left side controls the right side of the body, and the right side of the brain the left side of the body), this means that while the majority of the population is right-handed a have the brain areas in specific places, there are a number of people who have them on the opposite side due to their dominant hand being the left one (Hatta, 2007; Van Der Haegen et al., 2012; Rogers, 2021; Mutha et al., 2012).

1.3.1. Broca's Area

Broca's area is located on the frontal lobe of the left hemisphere, and some believe it plays a significant role in language production and comprehension as well as the coordination and involvement in "spoken word production, prior to articulation" (Flinker et al., 2015, p.2871). Nevertheless, some other scientists are not completely sure what the exact role of Broca's area is, and they speculate that it deals with movement (Stinnett et al., 2022) and speech articulation (Love & Webb, 1992).

Considering both sides, we could argue that Broca's area is somehow related to word production and articulation which would explain Broca's Aphasia, a language impairment that mainly deals with speech production (Whitaker, 2007).

Figure 2.
Broca's area.



(Retrieved from: https://www.flintrehab.com/damage-to-brocas-area/)

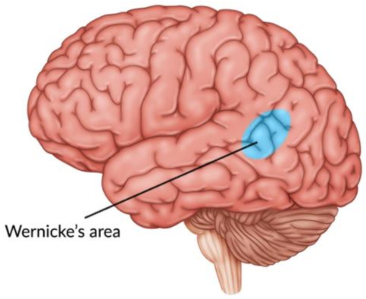
1.3.2. Wernicke's Area

Wernicke's area is also located on the left hemisphere, but on the temporal lobe. Nonetheless, the exact location is still somewhat conflicting and, according to Binder (2017), inconsistent. This area contributes to the comprehension of speech, and it was considered to somewhat participate in the 'formulation of internal linguistic concepts' (Love & Webb, 1992).

On the other hand, advanced technologies have shown that "this region plays a much larger role in speech production" (Binder, 2015, p.1) including language perception (Karbe, 2014). In this sense, we must mention that the connection between Wernicke's Aphasia, a language impairment believed to be connected to comprehension, has several underlying causes and conditions such as semantic impairment and deficits in acoustic-phonological skills (Robson et al., 2012).

All in all, it seems as though language comprehension is one of the main functions of the region, but not the only one since it is an intricate mechanism.

Figure 3.
Wernicke's area.

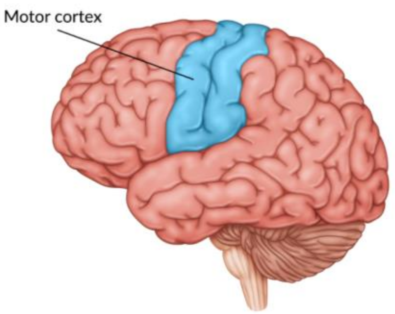


(Retrieved from: https://www.flintrehab.com/damage-to-wernickes-area/)

1.3.3. The motor cortex

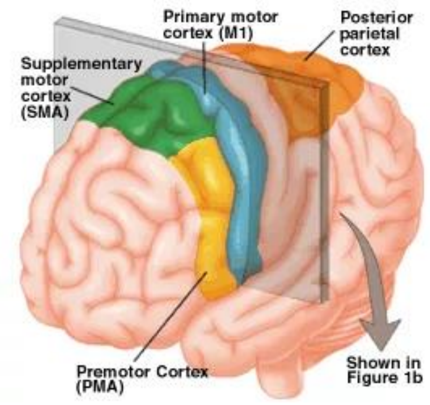
The motor cortex is a key region of the brain involved in the control of movement (Hikosaka et al., 2002). It is located in the frontal lobe and is divided into two primary areas: the primary motor cortex (M1) and the supplementary motor area (SMA). The primary motor cortex is responsible for the execution of voluntary movements (Penhune & Steele, 2012), while the supplementary motor area is involved in timing control, monitoring, and task switching (Hertrich et al., 2016). We must mention that both brain hemispheres have a motor cortex; and their areas control different movements (Guy-Evans, 2021a).

Figure 4.
The motor cortex.



(Retrieved from: https://www.flintrehab.com/stroke-in-the-motor-cortex/)

Figure 5.
Areas of the motor cortex and the posterior parietal cortex.



(Retrieved from: https://human-memory.net/motor-cortex/)

1.3.4. White matter

According to Guy-Evans (2021b), WM can be found in the subcortical tissues and the spinal cord. WM contains axons (nerve fibers) which are covered by myelin, which is what gives WM the white-ish color it has, and it is essential for the transmission of electrical impulses. This brain tissue helps with coordination and communication within the different brain regions. In addition, it seems as though WM volume changes amongst people. Douglas Fields (2008) says the following:

> "the extent of white matter varies in people who have different mental experiences or who have certain dysfunctions. It also changes within one person's brain as he or she learns or practices a skill such as playing the piano" (p.54).

Douglas Fields (2008) explains that WM volume changes depending on external stimuli or when someone learns something new. This shows that WM can be different for everyone due to the variety of experiences that each individual has.

Moreover, myelination of the neurons happens at different ages, and it seems to never be static (Buyanova & Arsalidou, 2021). In addition, people with different neurological conditions might have a “defect in the gene that regulates the production of this protein.” (Douglas Fields, 2008, p.54)

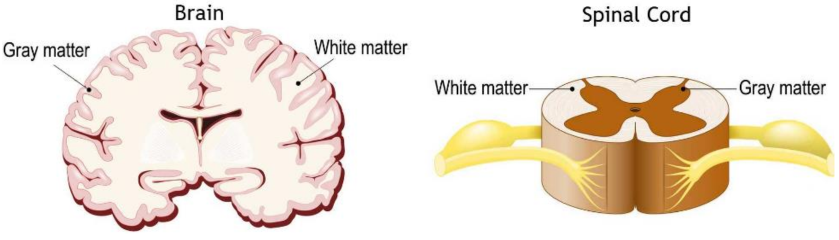
All in all, we could argue that WM has been considered essential for the connectivity of the human brain, even if it is still undergoing research (Sporns et al., 2005).

1.3.5. Gray matter

Another brain tissue that Guy-Evans (2023) talks about is GM, which can be found in abundance in the outermost layer of the brain, brain stem, and spinal cord. It occupies about 10% of the brain volume and is characterized by a pinkish/grayish color. GM consists of neuronal cell bodies (soma) which are connected to the rest of the brain through WM (*Brain Anatomy and How the Brain Works*, 2021). It forms the cortices of the brain, which are the *Cerebral cortex* and *Cerebellar cortex*.

GM is developed from birth up to the 8 years of age and after the brain is fully matured it slowly decreases in size starting between the ages of 30 and 35. Some of its functions are to control movements, retain memories, and regulate emotions. Nonetheless, it is also considered to be involved in information processing, personality, intelligence, organization, language processing, and motor function (Mercadante & Tadi, 2022; TEDx SFIT, 2020; *Grey matter*, 2023).

Figure 6.
WM and GM in the brain and spinal cord.



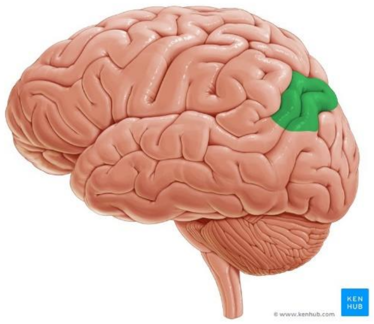
(Retrieved from: https://www.hopkinsmedicine.org/health/conditions-and-diseases/anatomy-of-the-brain)

__1.3.6. Angular Gyrus__

The Angular Gyrus is on the posterior part of the IPL (inferior parietal lobe). It functions amongst several networks that deal with attention, memory retrieval, self-processing, semantic information processing, emotion regulation, reasoning, visual symbols recognition, and spatial concepts. In addition, it seems to not be found in any other species besides humans. (Venkatakrishnan, 2014; Tanaka & Kirino, 2019; N., 2013). Furthermore, it is often connected to various diseases and impairments such as *Angular Gyrus Syndrome* and *Developmental dyslexia* (Valdois, 2010; Perry, 2014).

The Angular Gyrus is a very sophisticated part of the brain that is unique to humans. Many different cognitive processes, including attention and memory retrieval, are involved in its functions. However, it is also closely related to a number of neurological impairments and disorders. Further study into the Angular Gyrus will undoubtedly offer priceless insights into these conditions.

Figure 7.
Angular gyrus.



(Retrieved from: https://www.kenhub.com/en/library/anatomy/angular-gyrus)

1.4 Neuroplasticity

1.4.1 Introduction

Neuroplasticity, or brain plasticity, is an adaptive process of the brain that deals with structural and functional changes. Specifically, it has the ability to reorganize its structure, functions, or connections after injuries such as a stroke or a traumatic brain lesion (Li et al., 2014). These alterations can not only be beneficial but also neutral or detrimental.

Moreover, there are two mechanisms involved in the modifications. The first one is *neuronal regeneration*, also known as *collateral sprouting*. The second one is *functional reorganization*. The former, is a process by which damaged or lost neurons are replaced or repaired in the nervous system (Steward et al., 2012). The latter refers to the ability of the brain to adapt and change in response to injury or changes in sensory input (Henderson et al., 2011). It involves the recruitment of different brain regions to perform tasks that were previously carried out by damaged or affected areas (Wang et al., 2009).

Overall, neuroplasticity plays a fundamental role in the brain's aptitude to accommodate to injuries and changes. Therefore, these intricate mechanisms can prove to be significant in understanding of the recovery of patients suffering brain trauma such as damage after a stroke.

1.4.2 Change measurement

According to Li et al. (2014), there are three measures of anatomical changes: GM density, Cortical thickness, and WM integrity. These three measures will be elaborated on in the sections below.

1.4.2.1 GM Density.

Measuring the GM density is one of the most common procedures to analyze anatomical changes; this relies on VBM (voxel-based morphometry) by identifying the tissue after correction to find differences before compared to after. It is generally believed to reflect changes in cell size from neurons and glial cells. Nonetheless, it does not directly indicate the exact density of neurons, and it is not completely accurate (Li et al., 2014; Seminowicz et al., 2013; Yankowitz et al., 2021).

1.4.2.2 Cortical Thickness.

The measure of cortical morphology can be done by taking the distances between the nodes of the examined part. According to Li et al. (2014) this "provides sub-millimetre accuracy and takes into account the folding of the cortical surface" (p.3). Moreover, the thickness and structure of the brain has a significant role in normal development and aging (Dahnke et al., 2013). Therefore, it can be crucial to be able to measure it since it can provide with essential information of brain maturation.

1.4.2.3 WM Integrity.

Li et al. (2014) also state that WM integrity is measured by examining the water molecules in the brain using diffusion tensor imaging (Wang et al., 2009), or DTI, which compares the degree of diffusivity of neurons along the axon. Additionally, the measurement can also be done through RD (radial diffusivity) and MD (mean diffusivity). RD measures the water molecules that are in a perpendicular position, and MD measures the ones that are within a voxel. Nonetheless, the most common method according to them is FA (fractional anisotropy) which, essentially, measures the movement of water molecules in brain tissue through MRI (Rokem et al., 2017).

1.4.2.4 Neuroimaging Techniques.

In order for scientists to be able to measure all these brain changes, they use the various neuroimaging techniques mentioned in the paragraphs above (MRI, fMRI, EEG, MEG, etc.). It is worth noting that all of them serve their own purpose, and they are not the only techniques used in the field. Here is a brief explanation on some of the techniques and their various purposes.

Firstly, MRI uses magnetic fields and radio waves in order to produce images of the structure of the brain. fMRI is mostly used in order to study brain function and the mapping of neural networks by creating images of the changing brain flow. Moreover, EEG is a technique that used electrodes so as to detect electrical signs produced by neurons in order to monitor brain activity during cognitive tasks with the aim of understanding neural processes.

Lastly, MEG captures fluctuations of the electrical signs in the brain to measure activity. It is noteworthy that MRI and fMRI are more commonly used since they are less pricey compared to EEG and MEG, and that these are not the only neuroimaging techniques, but they are the most common ones (Crosson et al., 2010; Duyn, 2012; Kirschstein & Köhling, 2009; Hall et al., 2014). See appendices C, D and E for various representations of the scanners.

1.5. Language learning theories

1.5.1. The critical period

The critical period, also called *the sensitive period* (Yule, 2023), is a theory that states that there is a specific period of time when young children are more susceptible to learn languages. This sensitive period was firstly thought to be from birth until late childhood. Later it was extended until the teenage years. What this period would mean for the person learning languages is that after a certain age, they would not be able to learn languages at an almost native level (Bylund et al., 2020).

In order to support the CPH (critical period hypothesis), Locke (1994) stated that linguistic abilities develop through time and, thus, if there is any sort of delay in the learning of languages it would have long-lasting consequences. He adds that when children are unable to develop language in what it's considered a common timing and rhythm, it is unlikely that they will eventually fully develop it. Locke justifies all of this saying that the cognitive capacities for language are independent of the rest of the other brain mechanisms, and that since they develop in a different way there is no chance of recovering them when they have not been properly established in childhood. For the interpretation of Locke's view, see 1.5.2.1.

All things considered, there are different points of view in the CPH, but they all agree that when a child is not able to acquire languages adequately according to what would be the ordinary, it would be improbable to attain native-like proficiency.

1.5.2 Learning multiple languages during the critical period

What is believed about learning languages in the sensitive period is that it can lead to more native-like proficiency in the language and that it is acquired with remarkable ease (Birdsong, 2014).

On the other hand, what must be taken into account is that not everyone learns languages at the same rate and to the same extent. Hartshorne et al. (2018) state that achieving native-like proficiency during the stated "critical period" only means that the person learned the language fast enough since, as we mentioned before, everyone has a different personal experience. Therefore, it is worth mentioning that the CPH is being challenged, since the advantage it proposes (native-like proficiency) can be achieved as an adult. This is represented in the study Siddiqui (2016) conducted. In this study, Siddiqui aims to challenge the CPH and manages to show how an adult could, potentially, learn a second language at native-like proficiency. However, the fact that children learn very easily still remains unchallenged and true. This has to do with the fact that the brain is not yet fully matured, thus, still creating connections and learning. On the contrary, adults need a great amount of motivation and willingness to learn due to the nature of the aging brain that is slowly deteriorating.

All in all, it is only natural that when the brain is made to create, it is more susceptible to learning rather than when it is slowly declining.

1.5.2.1 Locke's view.

As stated previously in section 1.5.1 Locke supports the CPH, nonetheless, there are some faults in his arguments. He states that the mechanisms for language are developed differently than the rest of the cognitive functions, and this is now shown not to be like this due to the fact that the brain is a connected system (Power et al., 2011).

Furthermore, Locke emphasizes languages acquisition in children, not taking into account that adults could possibly learn languages too. It is not that he does not mention adults at all, it is simply a focus due to his belief in this critical period to secure the cognitive linguistic abilities. Therefore, adulthood should be taken more into account.

Moreover, as a result of not considering adult language learning, he also misses contemplating the stimuli adults could get in order to learn foreign languages. These confounding variables (age of acquisition, quality, and quantity of input, language immersion, etc.) have a great impact on the process and end result of the acquisition of languages (see below 1.5.5). For instance, it is currently more common to learn languages at any stage of the lifespan, and it can be justified in many ways (immigration, personal progress, brain training, etc.).

However, it was not so customary before by virtue of the language learning environments, since classroom learning was mostly available for younger people. Consequently, working adults were naturally not able to learn languages due to lack of resources, which is not a problem these days due to online learning material availability (Ruey, 2010).

On the whole, Locke had arguments substantiated for the moment he stated them. Nevertheless, nowadays, these arguments cannot be taken into consideration so as to support the CPH due to the fact that science has advanced, and language learning theories have as well progressed. Nowadays, it is common to examine how language acquisition changes with age and how the environmental influences it receives affect each person's experience and outcomes.

1.5.3 The localization view

According to Yule (2023), the localization view suggests that there are certain areas of the brain responsible for specific language functions, thus creating a pattern. According to this view, the brain’s left hemisphere is particularly important for language processing, with different regions responsible for different aspects of language, such as phonology, syntax, and semantics. Nowadays, some scholars argue that language is not limited to specific brain regions and that it is better understood as a complex process that involves multiple brain regions working together in a coordinated manner (Fedorenko & Thompson-Schill, 2014).

1.5.4 Types of Bilinguals and multilinguals.

Speaking multiple languages has always been compared to speaking one in order to state their differences. Nonetheless, this view has been thoroughly studied and is now undergoing a major change. The more it is researched, the more it is believed that there is not only a singular type of universal multilingualism and that there are various conditions that must be taken into account besides the fact that a person speaks multiple languages (Vári, 2021). Therefore, we must see which are some of the various types of bilinguals.

Firstly, there are *sequential bilinguals* who acquired first an L1 and after that, they learn an L2. Therefore, the acquisition of L2 starts while the process of acquisition of L1 is ongoing (Castilla et al., 2009). Another type is the *simultaneous bilinguals*; these acquire their L1 and L2 since birth. Nonetheless, there is a tendency for one of the languages to be the *heritage language* o also called a *minority language* and, as the name indicates, belongs to a minority group such as immigrants (Kupisch et al., 2014).

In addition, *compound bilinguals* can also be found. Bilinguals can be considered compound if they have learned simultaneously multiple languages during their childhood and, therefore, they are equal in their mind (Moradi, 2014). It is significant to mention that even if simultaneous bilinguals and compound bilinguals seem very similar, the main difference between them is the equality or inequality of the languages. In compound bilinguals, there is an equality of languages, but for the simultaneous bilinguals, there is one language that is considered minor than the other one due to social constructs.

Furthermore, there are coordinate and subordinate bilinguals. *Coordinate bilinguals* have acquired an L1 and an L2, and they use each of them in different contexts (Nacamulli, s. f.). This can be exemplified by a child who uses one language at school and a different one at home. Lastly, *subordinate bilinguals* are more commonly to be adults who are learning an L2 later in life by filtering it through their already acquired L1 (Moradi, 2014). These adults are more likely people whose brain is already fully matured, which affects the process of learning languages, and this is why they need to filter it through their L1.

1.5.5 Learning foreign languages in Adulthood

Learning a language in adulthood has undergone significant changes over the years due to advances in technology, changes in immigration patterns, and globalization. In the past, learning a language as an adult often involved traditional classroom-based instruction and a focus on grammar and vocabulary acquisition. This approach was very often slow, with little emphasis on practical communication skills.

However, in recent years, there has been a shift towards more communicative and interactive language learning methods. Advancements in technology have allowed for the development of online language learning platforms, language exchange programs, and mobile applications that offer users the opportunity to practice their language skills with native speakers from around the world. This has made language learning more accessible, affordable, and convenient for adults (Ahmadi, 2018; Ghanizadeh et al., 2015).

Moreover, there has been an increased focus on immersive language learning experiences, such as study abroad programs, language immersion camps, and homestays. These experiences allow learners to immerse themselves in the language and culture of their target language, providing a more authentic and meaningful language learning experience (Llurda et al., 2016; Goldoni, 2013).

Furthermore, taking all of these new methods and pathways to learning languages create multiple variables that affect not only the experience the learner has, but also the extent to which the person learns. Some of these variables are AoA (age of acquisition), SES (socio-economic status), as well as quantity and quality of exposure, and pragmatic need (Vári, 2021).

Overall, while language learning in adulthood has always been challenging, recent developments in technology and language learning methods have made it more accessible, interactive, and immersive, providing learners with more opportunities to practice their language skills in a real-world context.

1.5.5.1 Changes to the brain structure for mature adults.

1.5.5.1.1 Brain differences in different stages of adulthood.

The mature brain for different stages in adulthood is a complex matter that needs further research (Houston et al., 2014). Until now what is known is that there are very few variations in the brain of adults taking into account age differences (Pujol et al., 1993). Nonetheless, it must be stated that there are distinctions and that they can be somewhat related to age differences. However, it is unclear if that is the main cause or a lot of other conditions such as the situation and the level of concentration of the people partaking in a study is also involved (Grady et al., 2006).

All in all, brain dissimilarities are very notable comparing a child's brain to a teenager's one to the adult brain, but not taking into account extreme cases (recovery after a brain lesion for example) the variations seem to be minimal and caused by individual experiences rather than age. Nonetheless, as already mentioned, this area requires more studying in order to understand it better.

1.5.5.1.2 Brain training and language learning.

When the brain ages it atrophies, and it is more likely to develop neurological diseases such as Alzheimer's disease or dementia, mental illnesses like bipolar disorder, and even cognitive impairments (Cole & Franke, 2017). In order to postpone the consequences of cognitive decline, a person needs to stay physically active, maintain a healthy diet and learn new skills (see above 1.2.2 for more information).

Another thing that a person can do in order to delay cognitive deterioration is language learning, which has been established to improve cognition, self-esteem, memory, and attention. This improvement is achieved thanks to the reorganization of various brain mechanisms such as glial cells. Nonetheless, experts seem to not know if the changes are permanent since what is known now is that they are short-term (Klimova, 2018; Bubbico et al., 2019; Nijmeijer et al., 2021).

Overall, learning new languages is a positive experience in many ways. It can affect your brain and mind and, even if it is unclear whether the changes remain, it is extremely helpful to challenge the brain so as to avoid rapid brain decline. It is worth mentioning that most articles claim that this field needs further research in order to better understand the benefits and drawbacks of aging and brain training.

1.6 Research questions and Hypothesis

Based on the theory gathered, the research questions are the following:

1. Is there a difference between learning languages as a young adult compared to a senior adult?
2. Can anyone learn languages to the same extent?
3. Is the localization view still applicable?
4. Can the use of neuroimaging techniques provide insights into the neural correlates of language learning in adulthood?

The initial hypotheses, only based on the background information, are that the adult brain can learn languages to the same extent as the young adult and child brain except for the fact that it will have more difficulties due to the inevitable consequences of aging. Moreover, technological advances have a great impact not only on the way adults learn languages but also on the language learning theories. Furthermore, I believe the interviews will prove these hypotheses and, on top of that, add detail to the already found information.

2. Method

2.1 Participants

This study included a total of 2 participants who were recruited through direct communication initiated by the researcher. Both of them were contacted due to the nature of their jobs, since they are involved in the fields of cognitive science, neurolinguistics, language acquisition, and bilingualism.

The first participant has a bachelor’s degree in biology, a master’s degree in neuroscience as well as a Ph.D. Furthermore, he has multiple years of experience in the field of neuroscience since he started in 2016. He has worked with multiple methods to assess neural activity and language in the brain and is currently working as a full-time postdoctoral scientist in the Max Planck Institute for Psycholinguistics and has about 14 articles published in the cognitive science field. Moreover, he speaks 6 languages in total (English, French, German, Italian, Portuguese, and Spanish) and won an award for the best presentation in a Cognitive Neuroscience Conference in 2019.

The second participant has worked closely with the first one and has a similar background; he has a Ph.D. in Clinical Language Sciences and in 2018 was a finalist as Researcher of the Year for the University of Reading. He used to work as a Research Fellow for the Department of Psychology at the University of Birmingham and is currently working as an associate professor in the Department of Neurocognitive Bilingualism at The Arctic University of Norway. He claims that his research focuses on the different aspects that impact the brain when having bilingual experiences and that he studies how changes in language usage create cognitive adaptations. In addition, he has about 20 articles published in the cognitive neuroscience field, with a total of about 763 citations on Google Scholar.

Lastly, it is worth mentioning that both participants provided written informed consent prior to the interviews.

2.2 Materials

The materials used for conducting the interviews were a set of 12 questions that were personally created according to the research questions from this thesis and the background information. For both interviews, the same questions were asked. Nonetheless, both had different lead-up questions, to see the full interviews please see the appendices A and B. Furthermore, the instruments used for the whole process were Microsoft Word to create the questions and take notes from the interviews as they were happening, and Microsoft Teams to conduct the meetings. Lastly, Microsoft Outlook was also used for the purpose of contacting the experts and arranging the interviews.

2.3 Procedure

The scientists were contacted through Microsoft Outlook to get an interview done through Microsoft Teams. Both meetings happened on different days, but the procedure was the same; beforehand, a Participants' information sheet was provided in order to inform them about the topic and the reason for conducting such interviews.

The first interview was conducted on the 16th of February 2023 at 9 am. Once the participant was in the MS Teams call, the researcher explained the procedure and the interview started after the consent form was signed. The researcher asked each question and annotated the participants' answers on a Word document that was later revised so as to organize the answers and make them intelligible. It lasted a total of 1 hour and 15 minutes.

The second interview happened on the 17th of March 2023 and lasted a total of an hour. It was conducted in the same way as the first one: the researcher and the participant met online through a video call on MS Teams, the process was explained, and the consent form was signed afterward. The set of questions was asked, and every answer was annotated and, later on, revised and organized.

2.4 Ethical Consideration

This study was conducted based on the ethics guidelines of the Universitat Rovira i Virgili under the ethics approval number CEIPSA-2023-TFG-0006.

3. Results

Having described the methodology and data collection procedures in the previous section, this segment has a focus on the results from the interviews. It includes an analysis of the answers and the 12 questions, with a summary of the responses.

3.1 Interviews Results

A group of 12 questions was asked for each of the interviews. Here are the key findings for both.

When it comes to the first interview, participant 1 explained that the brain is made by multiple networks working together with the help of WM, since it allows successful connectivity throughout the whole organ. Moreover, he added that in order to track changes in the brain and neuroplasticity, there are neuroimaging methods such as MRI or EEG. As for the differences in brain due to age (child, young adult, and senior adult) the main one he stated would be size and connectivity since a child's brain is smaller and a young adult's brain is better in connectivity compared to a senior adult. Moreover, another difference is the function of the brain. The scientist claimed that, as a person grows, the brain reaches a cognitive peak at about 30 years of age, and after that, there is a slow but steady decline. Furthermore, to the topic of learning languages at different stages of the lifespan, he stated that, essentially, anyone can learn languages at any time, but it is easier and more common to learn them in childhood rather than late adulthood. If someone wanted to do so, it would take more time and be more difficult due to the deteriorating brain. Nonetheless, we must highlight that the first thing he stated was that it is possible to learn languages at all ages. Furthermore, it seems as though the brain has structural and functional changes when it comes to multilingualism and foreign language learning. On the other hand, the main differences are the external experiences that individuals have when acquiring a foreign language.

As for the second interview, participant 2 stated that the regions of the brain do not work individually but together. Moreover, white matter allows the various areas to work alongside and be connected. In order to track changes, participant 2 claimed that there are various ways of using the neuroimaging techniques: either longitudinally (studying a set of patients for a long period of time) or crossectionally (studying various population groups). This would mean that one could track the changes in groups speaking various languages or a group of participants that, throughout months (or years) they acquire foreign languages. Furthermore, the neuroimaging techniques mentioned by the second participant were MRI, fMRI, EEG and MEG. Moreover, it is worth mentioning that the scientist made a special focus on the fact that learning languages caused differences in the individual experiences rather than in the structure and function of the brain. Nonetheless, he mentioned that the internal differences are related to language control and the reliance on certain areas in order to perform various language tasks. In short, the second participant focused on specialization in the brain and how it varies depending on age, and that the main disparities when it comes to learning languages are the individual experiences rather than the brain structural and functional changes.

Overall, both participants said mainly the same things. Some answers varied when it comes to a short "yes or no" answer, but the justifications showed they were saying the same thing. Below the set of 12 interview questions with a summary of the comprehensive answers can be found.

Table 1

Interviews questions and answers.

Interview Questions	Answers
1: What exactly is your field of work? What does it consist of?	R1: I'm in the language and cognitive department. R2: Cognitive neuroscience and psychology with a focus on bilingualism
2: Do you think the various parts of the brain (involved in language) work on their own or do they all work together?	R1: It's definitively not individual parts working together. It's many networks working simultaneously. R2: The evidence shows that individual brain regions do not work together.
3: Do you believe that white matter is involved in language learning and/or processing?	R1: No, WM helps with connection, but processing doesn't happen in the WM. R2: Yes, it allows brain regions to work together.
4: How are scientists able to tell when a brain has changed? What are the processes involved?	R1: With neuroimaging tools such as EEG, MRI, spectroscopy, or TMS. There are more, and each is used for different exponents of brain behavior. R2: Through a longitudinal period with a scanner or EEG, or crossectional by looking at adaptation along the population.

5: What are some common methods for scientists to measure the changes in neuroplasticity?	R1: MRI and EEG. R2: MRI, FMRI, MEG and EEG.
6: What, if any, are the differences between an infant brain and an adult brain?	R1: The size and the connectivity. R2: A lot, mostly dealing with how the brain specializes (the connection and morphological differences).
7: What, if any, are the differences between the brain of a young adult and an aging brain?	R1: The cognitive peak is reached at around 30 and then there's a steady decline. R2: One is developing and the other one is degrading.
8: Do you think there is a big difference between learning languages when you're a child vs an adult?	R1: As a child, it's more common. Adults learn languages because they actively try. But anyone can learn a language at any time. R2: Language is more fully formed depending on the age you acquired it and there are environmental differences as well.
9: And a young adult compared to an elderly?	R1: Older people have it more difficult since language learning requires capacities that, for them, are deteriorating. R2: The main differences are external, but there could be slight internal ones.

10: How does the brain of a sequential bilingual differ from a foreign language learner?	R1: At the brain level, there are not many differences. Individual experiences are what change. R2: In the function of their experience, the amount of exposure, the intensity of exposure, how many people are they getting the language from, the context of the learning, and more.
11: How does being bilingual affect the adult brain?	R1: In young adults, it seems to lead to structural function and chemical adaptations. R2: Mainly in language control, but also brain function and cognition.
12: Does the brain of adults change if they start to learn foreign languages? If so, how?	R1: Yes, but the change also depends on the level of the learner. R2: Yes, it does. The reliance on different regions will increase or decrease and the system will want to make language as efficient as possible.

In the next section, the interviews will be interpreted in depth, in reference to the research questions, in order to show their relevance to the study.

4. Discussion

According to Klimova (2018), Bubbico et al. (2019), and Nijmeijer et al. (2021), learning foreign languages is significant in order to benefit from multiple cultures, promote healthy aging, prevent neurological clinical conditions and improve not only your self-esteem but also your attention and memory. Moreover, according to Li et al. (2014) the adult brain undergoes through various changes when learning foreign languages. These are mainly an increase of GM density and WM integrity. This section will discuss the research questions which deal with the various aspects of learning languages and the neuroimaging techniques scientists use to observe brain changes. In each of the subsections below, the background information and the methodology of this thesis are thoroughly interpreted.

4.1 Learning languages in different stages of adulthood

When it comes to learning languages, everyone has a different experience. According to the background information, there are many variables that can affect the language learning process (Vári, 2021). The first research question asked if there is a difference between learning languages in young adulthood compared to late adulthood, this was answered by the experts interviewed.

It seems as though, in the past, learning languages was a progress that a person could undergo in a classroom environment. Nonetheless, nowadays, it is known that there is a lot more to it and the experiences and methods used can vary. Since there have been many technological advances, not only have there been plenty of opportunities and resources for people to learn languages, but also for scientists to further detail their research and gain more knowledge in this area. This has proved to be extremely useful since, before, there were many people who were not able to learn foreign languages for personal developmental reasons due to lack of resources. However, it is now clear that anyone can do so since; because of all the new apps, webpages, and online teaching resources; availability of learning material has greatly increased.

As already mentioned, there are many factors that influence the uniqueness of each experience. These factors that were stated in the background information section were supported by the scientists. For example, there is the age of acquisition factor, or AoA, where there is a difference in language learning between a 7-year-old child, a young adult reaching their cognitive peak and an 80-year-old adult doing so. This is because of the nature of the brain and the period of time where it functions in favor of learning.

Furthermore, the quality and the quantity of the input one receives of the language intending to learn is crucial. This means that if the learner is immersed in a context where the only language spoken is the one wanting to learn, they will have a different experience and outcome compared to someone who is learning in a class environment. In addition, the SES (socio-economic status) is significant due to the fact that not everyone is able to access all the existing resources. This is because some opportunities such as exchanges, and abroad stays are only available for a certain amount of people since most of them need to be financed either fully or partially by the one going abroad. This implies that the quality and quantity of exposure to the foreign language will be greatly influenced by the amount of money you are able to spend on it.

All of those variables are major aspects when it comes to studying another language. It is true that age seems to be a main concern for people willing to learn, but the fact that there are many more matters influencing the extent of the learning experience must be taken into consideration. In this regard, it is true that it is different learning languages as a young adult or as a senior adult because it would probably take some more time and effort, but the main difference would be the encounter with the language that primarily impacts the process rather than the age itself.

4.2 The human extent of language learning

In the previous section, it is mentioned that the main disparities in terms of learning languages are the individual experiences. The second research question asks whether anyone can learn languages to the same extent or not. The view that everyone can was supported by the background information as well as the scientists that were interviewed.

In the first half of this thesis, it is stated that since humans are born and until the 25 years of age, their brains are creating connections. Afterward, the brain slowly but steadily declines along with the body. With this information, it could be inferred that there must be a biological difference between someone who is learning languages during the teenage years and someone who learns them later in life, but this is not the case. On the one hand, it is true that age of acquisition has an impact on learning foreign languages. This is because of the cycle of the brain life mentioned before: from creating connections to slowly destroying them (Bherer et al., 2013; Giedd, 2015). It is instinctive to think that when the brain is working hard in order to create connections, and it is more sensitive to input, it makes it extremely easy for the person to acquire knowledge (being from a new skill or a language).

On the other hand, the age of acquisition is not the only factor affecting foreign language learning. There are many variables that can cause having one experience or another (see above in 4.1 and 1.5.5 for further detail) which causes each individual to have various encounters with the foreign language, this way affecting the outcome (Llurda et al., 2016).

Moreover, the goal of language learning must be taken into account, no matter if it is achieving the basic level of the language in order to travel for holidays or a native-like proficiency for personal reasons. According to the scientists interviewed, anyone can achieve their language goal (even if everyone has the goal of achieving a native-like proficiency) since the brain is predisposed to do so. The main difference between someone who would like to achieve it at a younger stage of life compared to a latter one would be the individuality and ease of learning. As mentioned before, the age affects the propensity of the brain to learn with more ease or less, which would mean that learning later in life means a greater difficulty (Birdsong, 2014). However, it does not necessarily imply that learning the new language would be impossible.

Overall, it seems as though everyone can learn languages to the same extent at any stage of life if they surround themselves by the right environment for it, considering the circumstances they live in. It is very likely that being older will require more motivation and external qualitative and quantitative input in order to achieve a native-like proficiency. Nonetheless, it is definitely attainable.

4.3 Applicability of the localization view

The localization view states that language has a pattern in the brain and, therefore, the working regions of the brain can be traced when it comes to speaking one or multiple languages. After all this time, and due to advances in technology, it could be that one of the most popular language theories has been estimated to be outdated. The third research question asked if the localization view is still applicable nowadays, which was not supported by the interview answers.

It is true that certain brain areas are specialized more in certain language skills, some of them can be seen above in section 1.3 (Price, 2012). However, it would be a mistake to think that these are the only parts of the brain working for the various purposes of language acquisition and production. In the background information section of this thesis, there are already hints that the view is being challenged, this is for example the case of Broca's Area and Wernicke's Area since they have been, for a very extended period of time, considered key areas when it comes to language. Nonetheless, they are nowadays being questioned and revisited due to the fact that scientists are trying to fully understand the specialization and functioning of these areas and how these functions are connected to a bigger picture in the language network in the brain (Stinett et al., 2022; Binder 2017; Love & Webb, 1992). In addition, in the interviews there was the question of whether the brain mechanisms work individually or together, and the answers were conclusive that all brain regions work together since it is never various parts working alone. On top of that, both experts said that the brain is conveyed by various networks working simultaneously.

Moreover, evidence from neuroplasticity and left-handed people shows that not all brains are the exact same since brain regions and specializations can move from one place to another one. This can be seen in brains that have had damage to a region of the brain and after recovery, the patient is still able to live like they did before the damage happened (Hatta, 2007; Van Der Haegen et al., 2012; Rogers, 2021; Mutha et al., 2012). It can also be seen in the fact that left-handed people have the brain areas and functions on the other hemisphere compared to what most of the population has.

Overall, the implication seems to be that there is a steady advance in the neurolinguistics area since it is questioning and revisiting theories taken as true for a considerable amount of time. Nevertheless, it is significant to state that this seems as though it is a slow process that is still in progress and further research could definitely provide with relevant additional clarification in order to fully understand the complex dynamic networks that the brain consists of.

4.4 Neuroimaging Techniques

The fourth research question asked whether neuroimaging techniques can help determine the changes in the neural structure of the brain for adults learning foreign languages. Considering the background section and the interviews, this question was supported.

It is true that there are many technological advances nowadays in the science fields, and one of them is neuroimaging techniques. There are many of them that serve different purposes, and they can serve as support to scientists in order to track changes in the brain. It must be stated that there are no machines nowadays that specifically track adaptations, instead scientists use the tools available to detect certain brain activity at different times. This means that when brain changes want to be tracked, scientists take a specific task and observe the brain activation and patterns. After that, they switch tasks, and they view whether the brain activation is different or not. This is possible due to the various machines and neuroimaging techniques available such as fMRI, MRI, EEG or MEG. These are the most common ones in neurolinguistics articles and the ones that were mostly mentioned by the scientists interviewed for the purpose of this thesis.

All in all, the different neuroimaging techniques are definitely an asset when it comes to observing and tracking brain changes. Nonetheless, only using them would not be enough since the images need to be interpreted by a professional.

4.5 Study importance

This study has shown the conditions, effects, and possible outcomes of learning languages throughout the lifespan. It is significant to mention that many topics in the area are still under research or under revision in order to advance and, eventually, have more details. Nonetheless, more people should be taught about the benefits of training the brain through skill learning, since it would be extremely advantageous so as to understand how humans can promote healthy aging and make it a habitual practice. This would make the implication of delaying many neurological conditions and reduce the risk of higher cognitive impairment later in life and encourage cognitive well-being. Moreover, it could also be helpful aiming to boost body and mind understanding for everyone since it would provide with favorable knowledge in order to help people to be more conscious of their actions and reactions.

4.6 Limitations of the Study

Limitations are an inherent aspect of any research study, and this bachelor thesis had some: the reduced number of participants, limitation of data accessibility, and progression of research. As for the participants, there were only two of them and the number could have been greater so as to broaden the scope and point of view of the information. Moreover, the resources were also restricting due to the fact that, as a university student, the availability of resources is limited. This is because there are many journal articles that need to be paid or supported by the institution one studies in. However, having a larger number of resources could have provided with more insight into the several segments of this thesis in order to make it even more complete. Furthermore, there were many aspects researched that are currently undergoing revision and reshaping by scientists, which means that some information may be contingent on the time and period of the research. Lastly, it is worth mentioning that the data and results from this paper is part of a bachelor thesis not a scientific study, thus, the information is directly linked to the purpose of the context rather than to serve as a generalization in the neurolinguistics area.

5. Conclusion

Foreign language learning is a common practice that most people do throughout many cultures and ages. Furthermore, it has always been an interesting area to research since it allows making sense of certain brain mechanisms that otherwise would be unknown, and it helps to partially comprehend the complex organ that the brain is. For these reasons, it has been extensively researched for several decades. This thesis was designed to provide a theoretical background to various aspects and theories of neurolinguistics and prove or disprove various theories within the current knowledge of experts in the field. Taking this into consideration, it must be stated that not only did the insights provided by the scientists completely aligned with the initial hypotheses on language learning in adulthood, but they also contributed into giving an insight into the present information in the neurolinguistics field. All in all, it is crucial that people understand their ability to learn languages at a full fluency level at any point of their lifespan because they have always been told they cannot do so when they could be benefiting from acquiring new knowledge, interculturality, and better cognition.

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Appendix A

First Interview

1) **What exactly is your field of work? What does it consist of?**

It has switched in the past, I did a Ph.D. in the science of multilingualism, studying cognitive, brain change, MRI, and egg studies. Looking and how the brain or if the bilingual brain adapts when you have different populations with different language uses and how the brain adapts. I'm currently still working on it and supervising a Ph.D. student, but I'm in the language development department. He looks into language and cognitive development (how people and the brain develop with languages); basically, he has a similar job but with a different population focus (from adults to children).

1.1) Do you find it hard to do this population shift?

Not at all, it's actually quite interesting since there's a big gap to work on because there is a lack of literature, and you feel like you can fill in the gaps.

2) **Do you think the various parts of the brain (involved in language) work on their own or do they all work together?**

It's a network, nothing works on its own in the brain: not related to language not related to anything. The approach that everything works together is strengthening in the sense that it is more and more believed that everything is connected. What is more, it is believed that it is not only one network but many of them working simultaneously. It is definitively not individual parts working together.

3) **Do you believe that white matter is involved in language learning and/or processing?**

Processing doesn't happen in the WM at all, it just helps to connect (allows the signal to get dispersed). White matter allows communication to flow effortlessly. WM is heavily involved in how the system works. There can be seen adaptations on the corpus callosum because of bilingualism and multilingualism, but it mainly happens in the GM.

What happens with WM is that it adapts because you need more or less thickness in different parts. The more you have the better everything works; it is like the rubber around cables that helps electricity to run around and not get dispersed.

4) **How are scientists able to tell when a brain has changed? What are the processes involved?**

Neuroimaging tools that allow mapping behavioral and neuronal changes. Learning doesn't happen out of the blue and improving technologies allow scientists to see that.

Egg is normally used for physiological changes but there are others: MRI, spectroscopy, … There's also TMS, which is like a coil that focuses some rays on a specific brain region, and for a specific amount of time it deactivates the region and then you can see the behavioral changes. Nonetheless, all of them have advantages and disadvantages and all of them look at different exponents of brain behavior which means that depending on your research you use one or another one.

5) **What are some common methods for scientists to measure the changes in neuroplasticity?**

MRI, you can see the structure and functional changes; you can also see neuroplasticity (WM and GM). EEG, similar to MRI but with spatial resolution, doesn't show neuroplastic changes specifically. EEG is not made for this but there's low or high resolution: high resolution that allows you to see changes and trace them from where they come from. With this you see the change but not the origins; one cannot know exactly what is happening because you cannot see it directly, but there are changes that can be interpreted.

6) What, if any, are the differences between an infant brain and an adult brain?

Size, the brain stops developing at around 30 (cognitive decline) 30/35; everything happens before birth until one is 30 or 35 years old.

Connectivity, when you have a lesion, your brain can adapt to it by strengthening the connective pathways; the internal structures adapt and continuously evolve. Before birth you are not so exposed to language, but once you're born, you're incredibly exposed to languages, then one slowly starts picking up information and rewiring to store and make sense of it.

We are born as universal listeners. We are born to learn any language until a certain point (6 months-1year). Maturation process from 0 until you die.

6.1) If you're a simultaneous bilingual does this point happen the same way as multilingual?

There was a claim that bilingualism is bad because one can 'fall behind'; It was seen as something bad for children and for their brains. But this view was put aside slowly. Sometimes people still believe this. However, nowadays we know that it's not like this, even if your brain has to work more because of these different inputs. If you compare it, bilinguals don't have the same amount of vocabulary as monolinguals, however, if you take their vocabulary from their L1 and L2 it is way bigger in amount than the one from a monolingual. Children obviously make mistakes, but it is not a bad thing. The brain cannot avoid it. It is not at all harmful; it's positive if anything.

6.2) What when adults make these language mistakes of not finding a word?

It's more artificial, for children it just comes naturally.

7) **What, if any, are the differences between the brain of a young adult and an aging brain?**

The cognitive peak is reached at around 30; there's a steady decline from then on in cognitive abilities. It comes because there's a decline because the whole system is getting older, and it shrinks.

7.1) Is there a way of avoiding it or postponing it?

You cannot avoid it; we cannot stop aging. There are ways to keep your brain fit; lifestyle activities can help postpone and slow down this decline (physical activity, playing an instrument, healthy diet, speaking more languages, …)

8) **Do you think there is a big difference between learning languages when you're a child vs an adult?**

Learning during childhood is more common. As a child, you learn languages by external explicit input and you suck up the information you get. However, as an adult it usually happens because you actively try to learn a language.

Overall, one can learn a language at any point in time and at almost native-like level. The brain can process an L2 similarly to L1, but the main difference will be that, because phonology is the most difficult thing to process, you will very likely have an accent.

9) **And a young adult compared to an elderly?**

Older people have worse memory systems so it will make it more difficult. And learning a language requires capacities that are deteriorating, e.g. memory. In general, there are differences but you can learn a language even when you're 70.

10) **How does the brain of a sequential bilingual differ from a foreign language learner?**

It's hard to answer because literature is still shifting the look at bilinguals and monolinguals. Different bilinguals entail different ways of interacting with different languages, and this obviously leaves marks on the brain. In general, at the brain level, there is not much of a difference, but individual experiences are what change. How much you're exposed to and use the language, what are the ages of acquisition, immersed environment, …

11) **How does being bilingual affect the adult brain?**

In young adults, it seems to lead to structural function and chemical adaptations at the language system and substantial parts of the brain. Both adapt well due to bilingualism. However, it is a big debate.

12) **Does the brain of adults change if they start to learn foreign languages? If so, how?**

Yes, it changes at least the processing. It must have consequences depending on being a beginner, advanced, or intermediate learner.

Appendix B

Second Interview

1) **What exactly is your field of work? What does it consist of?**

Cognitive neuroscience and psychology; with a focus on bilingualism. I focus mainly on how variations in bilingual experience affect brain function and structure throughout the lifespan.

2) **Do you think the various parts of the brain (involved in language) work on their own or do they all work together?**

The evidence shows that individual brain regions do not work alone. There are contributions of individual brain regions into networks. Some regions are more implicated than others, but all need to work together. Nowadays, it is thought that there are more regions involved than it was originally thought.

3) **Do you believe that white matter is involved in language learning and/or processing?**

WM allows different regions of the brain to work together; it is like the insulation on an electrical wire. In short, yes WM is involved but we must bear in mind what we mean when we say those things.

4) **How are scientists able to tell when a brain has changed? What are the processes involved?**

There are various ways to do this: to directly measure changes one can look at someone's brain on multiple occasions (longitudinal period: through scanner or EEG and then they will be in a specific context where you expect a change to happen. After this time in between, you scan them again and then you compare brain structure at time 2 vs brain structure at time 1. Then, assuming there has been a change, you would see changes in size, connectivity patterns, morphology, …

You can also look at adaptations along population (also called crossectional). Recruit participants, get informed about their background, identify and calculate key variables of experience, take brain scans of them and, then, use a form of regression analysis and see if specific changes have occurred. You cannot track changes but you can identify pathways and patterns in this way comparing with.

5) **What are some common methods for scientists to measure the changes in neuroplasticity?**

There are 3 that are predominantly in the field: MRI (the best measure at the moment) and fMRI, to look at brain structure. Brain patterns with EEG (you put electrodes on a participant's scalp, it picks up microvolts of electricity from neurons, takes it to some amplifiers and it digitalizes on a computer; can be analyzed at a resting state (also with MRI); measures how the brain is functionally organized; you can also use it how it is most commonly used for - how the brain is recruited to handle language processing. To measure brain activity with stimuli when something happens; you can learn how the brain processes by stressing the system),
Another way is MEG (magnetoencephalography) which collects information about the changes in local magnetic fields. Each of these can be used but you need to understand the advantages or disadvantages.

6) **What, if any, are the differences between an infant brain and an adult brain?**

There are a whole host of differences. Most have to do with the way the brain specializes.

Infant: up to 6 new connections being born, this is very demanding to keep active and energy inefficient. Mid to late childhood up to 25: the previously needed but now the not needed connections get disconnected, the cortex thins, and from 20 years to 25 years, gets more stable

Overall, we could say that the main differences are the connections in the brain and the morphological differences.

There are also things that are not different: the way a brain has formed in the uterus does not change. What happens is at a certain point functions lateralize, connections grow, and areas specialize.

7) **What, if any, are the differences between the brain of a young adult and an aging brain?**

One is developing and the other one is degrading. After about the mid-thirties the brain is no longer optimized and it slowly starts to degrade. Then, in the mid-sixties it degrades even more (memory, …). For the majority of the population it is not a clinical issue; however, in serious cases, some brains degrade more rapidly and can have clinical implications (Alzheimer, Parkinson, …)

In conclusion, as you grow up there is development and optimization, but as you age degradation is a natural thing just like it happens with the body.

8) **Do you think there is a big difference between learning languages when you're a child vs an adult?**

There are some differences: language is more fully formed depending on the age when you learn it; there are also environmental differences.

In terms of language, there are some milestones that, regarding age, you still acquire. Children have similar patterns as adults no matter the language or the age; the rate at which you get is different, but they have a similar order

9) **And a young adult compared to an elderly?**

There are a lot of factors to take into account besides age (external factors) it is more complicated than only the age of acquisition: motivation, involvement, environment, …

The main differences are external, but there could be slightly internal ones too.

10) **How does the brain of a sequential bilingual differ from a foreign language learner?**

They differ in the function of their experience, the amount of exposure, the intensity of exposure, how many people are they getting the language from, the context of the learning, and more.

At a certain point in adulthood (depending on experience):

- Early: outside a classroom setting; motivation
- Late: depending on when you test the people; mainly in the classroom, exposure is limited, whom are they getting exposed to, how often, if they engage outside a classroom or not, …

Brain differences are going to be tight with the nature of the experiences from the languages they speak and, of course, it depends on when you test them and what individual external experiences they have had.

11) **How does being bilingual affect the adult brain?**

The predominant thing is language control. When you have multiple grammars, they all have to be active to some degree; you need to be able to use any language anytime and it creates a competitive environment. Selecting languages will lead to fluctuations in brain structure and function to make this adaptation control easy and simple. The languages seem to be stored in similar ways, so it is a matter of using the languages.

Brain function and cognition are also affected: just having the additional language is not enough to see adaptations. There will potentially be differences between monolingual and multilingual with how the brain is able to make languages engage.

11.1) What happens in the brain when you have TOTT (tips of the tongue) - you cannot come up with a word with one language but you can in another one?

The word might be more activated than another one, it shows that you have these active systems.

12) **Does the brain of adults change if they start to learn foreign languages? If so, how?**

Yes, it does. You have to deal with the new rules of lexis and that should require additional demands on language processing and control (if you don't have other languages already). The reliance on different regions will increase and decrease depending on how long you learn the language. Moreover, a function of optimizing and making it as efficient as possible language processing and control also gets activated. Overall, a lot is happening, but these are the underlying demands that need to be met.

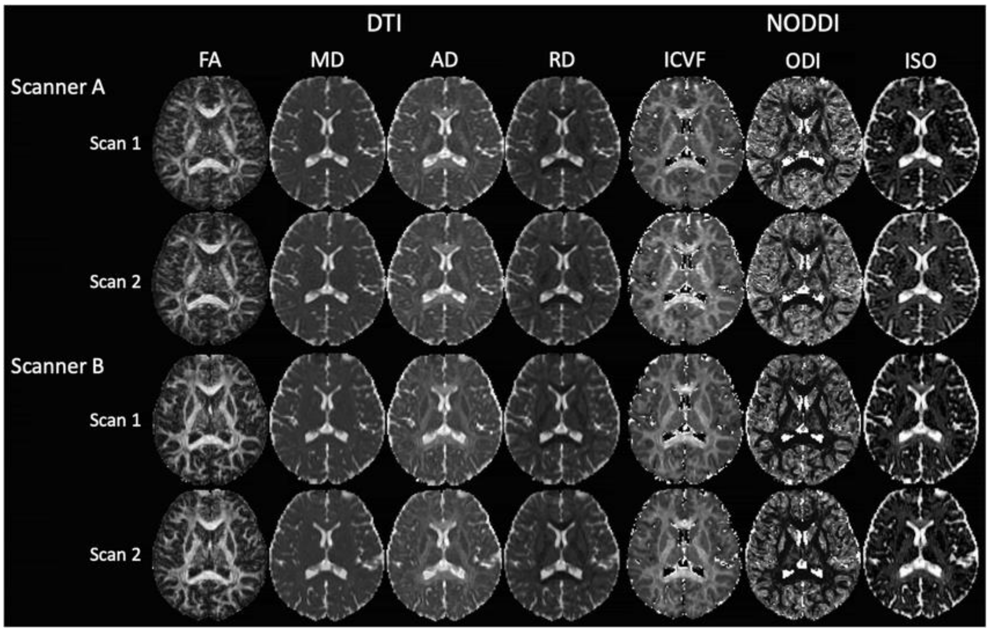
However, it depends on how you look at brain function, structure and patterns.

Generally speaking, you need to build a new grammar and develop a different representation and there will be cross-linguistic effects, slowly learning more about how it looks like in the neurolinguistics field and cognitive field.

Appendix C

Representation of various scanners.

Figure 8.
MRI scanners of FA, MD, RD, and others.

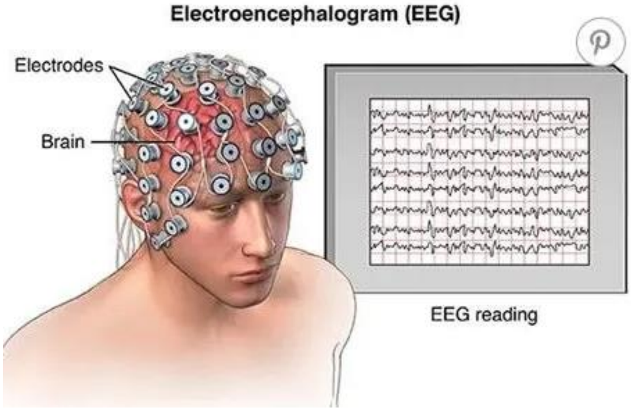


(Retrieved from: https://www.researchgate.net/figure/Diffusion-tensor-imaging-fractional-anisotropy-FA-mean-diffusivity-MD-axial_fig1_338196530)

Appendix D

Representation of EEG.

Figure 9:
EEG representation.

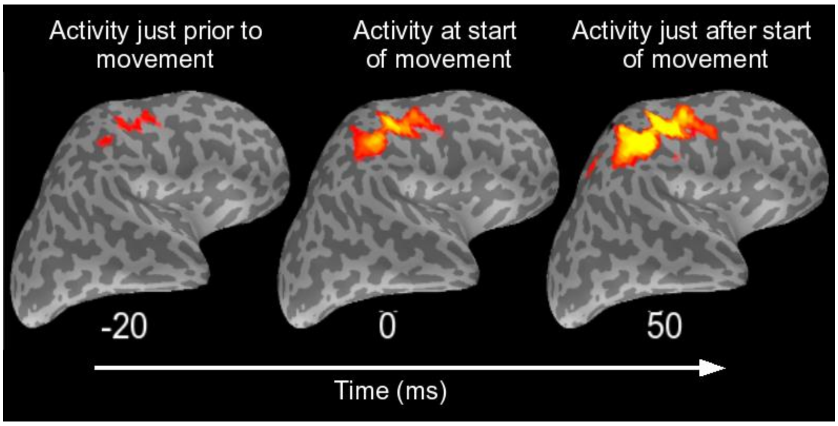


(Retrieved from: https://www.brightbraincentre.co.uk/electroencephalogram-eeg-brainwaves/)

Appendix E

Representation of MEG.

Figure 10:
MEG scanner representation.



(Retrieved from: https://www.nmr.mgh.harvard.edu/neurorecovery/technology.htm)