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LETTERS

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BILINGUALISM AND COGNITIVE RESERVE IN AGING: THEORETICAL, BEHAVIORAL AND BRAIN EVIDENCE

Porto Alegre
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Monograph presented as a partial requirement for obtaining a Teaching Degree in Language Arts: English from the Language Arts: English course at the Pontifical Catholic University of Rio Grande do Sul.

Advisor: Lilian Cristine Hübner, PhD

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ABSTRACT

The aging population, especially in Brazil, has become a priority for the health, economy, and social security sectors due to the global increase in life expectancy and population growth. It is predicted that by 2050, one in six people worldwide will be over 65, which raises concerns about the heightened risk of dementia. Recent studies have introduced the concept of cognitive reserve, which is the brain's ability to maintain cognitive function despite age-related changes or damage. Bilingualism has been identified as a potential factor that could enhance cognitive reserve, indicating that bilingual individuals may have a lower risk of cognitive decline as they age. Therefore, the aims of this paper were (1) to verify how bilingualism impacts cognitive performance in aging, regarding linguistic and other cognitive constructs such as memory, executive functions, and attention; (2) to verify how bilingualism impacts the aging brain structurally and functionally. Through a comprehensive literature review, this monograph explores the role of bilingualism in cognitive reserve during the aging process, regarding behavioral and neuroimaging evidence. It explores the impact of bilingualism on cognitive performance, brain structure, and function. The monograph concludes that while there are varying perspectives on the matter, it is crucial to recognize that bilingualism can serve as a valuable cognitive reserve, with important implications for cognitive neuroscience and overall health outcomes.

Keywords: bilingualism; cognitive reserve; aging; brain structure; brain functioning.

RESUMO

O envelhecimento populacional, principalmente no Brasil, tornou-se uma prioridade para os setores de saúde, economia e seguridade social devido ao aumento global da expectativa de vida e crescimento populacional. Prevê-se que até 2050, uma em cada seis pessoas em todo o mundo terá mais de 65 anos, o que levanta preocupações sobre o risco aumentado de demência. Estudos recentes introduziram o conceito de reserva cognitiva, o qual é a capacidade do cérebro de manter a função cognitiva apesar das alterações ou danos relacionados à idade. O bilinguismo foi identificado como um fator potencial que poderia aumentar a reserva cognitiva, indicando que indivíduos bilíngues podem ter um risco menor de declínio cognitivo à medida que envelhecem. Portanto, os objetivos deste artigo foram (1) verificar como o bilinguismo impacta o desempenho cognitivo no envelhecimento, no que diz respeito à linguagem e outros construtos cognitivos como memória, funções executivas e atenção; (2) verificar como o bilinguismo impacta estrutural e funcionalmente o cérebro envelhecido. Por meio de uma ampla revisão da literatura, esta monografia explora o papel do bilinguismo na reserva cognitiva durante o processo de envelhecimento, considerando evidências comportamentais e de neuroimagem. Este trabalho também explora o impacto do bilinguismo no desempenho cognitivo, estrutura cerebral e função. Conclui-se que, embora existam várias perspectivas sobre o assunto, é crucial reconhecer que o bilinguismo pode servir como uma reserva cognitiva valiosa, com implicações importantes para a neurociência cognitiva e resultados gerais de saúde.

Palavras-chave: bilinguismo; reserva cognitiva; envelhecimento; estrutura do cérebro; funcionamento do cérebro.

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1 INTRODUCTION

Being a scholarship holder from 2020 to 2023 as a member of GENP (Group of Studies in Neurolinguistics and Psycholinguistics) - conducted by my advisor - allowed me to dive deeper into psycholinguistics and neurolinguistics studies. Furthermore, during the period I was a scholarship holder, I got the chance to work on projects of a linguistic-cognitive stimulation program for adults and older adults, which provided me with a broader understanding of the aging process and its effects on the brain, cognition, and lifestyle. Also, I have been teaching English as a second language to a wide age range, from kids five years old to adults 70 years old; therefore, I have been able to see bilingualism in different brain structures, and this has always fascinated me. Thus, when I had to choose a theme for my monograph, bilingualism and brain were always a choice, then considering the social and economic scenario of the growth of the aging population and my recent work with a program for linguistic-cognitive stimulation for older adults, the topic of my monograph had to be a combination of these study areas that are so interesting to me.

Throughout this monograph, it is important to note that the bilingualism framework being utilized is the Language Modes framework by François Grosjean. This framework plays a crucial role in comprehending bilingualism by emphasizing the adaptable and flexible nature of language use in bilingual individuals. According to Grosjean, bilinguals are not two separate monolinguals in a single person. Instead, they possess a unique linguistic configuration and use their two languages to different extents based on the situation, topic, and interlocutor. The central concept of the Language Modes Framework is that bilinguals can exist on a continuum of language modes at any given moment, ranging from entirely monolingual mode to a fully bilingual mode.

The growth of the world population and the increase in the average life expectancy in Brazil and in the world have led many sectors of society, such as bodies responsible for health, economy, and social security, to pay special attention to aging (TAVARES; NETO, 2020). With the population aging, it is predicted that one in six people in the world will be aged 65 years or over by 2050 (UNITED NATIONS, 2019). This change in the demographic profile is accompanied by new concerns, such as, for example, the considerable increase in the risk of dementia (MITREČIĆ *et al*., 2020) as a consequence of advancing age. In recent years, studies on the concept of cognitive reserve have emerged as a key area in the field of aging, since it refers to the ability of the brain to maintain cognitive function despite age-related changes or brain damage (STERN, 2009). Bilingualism has been pointed out as one of

the factors that may contribute to an increase in cognitive reserve, suggesting that bilingual individuals may therefore have a reduced risk of cognitive decline in the aging process (BIALYSTOK, 2021).

In the new global economy, one might say that being bilingual is not an exception, it is the norm. Therefore, in this paper, we aim to investigate the role of bilingualism on cognitive reserve in aging, considering behavioral and brain evidence through a literature review looking for evidence that supports our thesis. Taking all these factors into consideration, the aims of this paper are (1) To verify how bilingualism impacts cognitive performance in aging, regarding linguistic and other cognitive constructs (memory, executive functions, attention), (2) To verify how bilingualism impacts the aging brain structurally and functionally. As for the research questions, (1) How does bilingualism interact with cognitive reserve in aging? (2) What are the behavioral and neuroimaging correlates of bilingualism as a source of cognitive reserve?

This monograph is organized into five chapters. In Chapter one, we introduce the aims of this paper, the questions that guide our research, as well as an overview of the concept of cognitive reserve, and the evidence on the cognitive benefits of bilingualism in the aging process. In Chapter two, we present the concept of cognitive reserve in aging, defining and specifying sources of cognitive reserve and stating what is the role of cognitive reserve in postponing cognitive decline and dementia. In Chapter three, we present the relationship between bilingualism and cognitive reserve, discussing the impact of bilingualism on cognitive performance; it also explores the advantages and disadvantages of being bilingual. The fourth chapter discusses the role of bilingualism in brain structure and functioning, with evidence suggesting that bilingualism can enhance cognitive reserve and neural plasticity, potentially helping prevent age-related cognitive decline. It also discusses how bilingualism reshapes existing networks, activates more parts of the brain, and improves functional connectivity. The final chapters provide a discussion of the findings and final thoughts on the topics covered in the paper, followed by the references used as basis for the present paper.

By synthesizing the findings from both behavioral and brain studies, this monograph offers insights into the mechanisms underlying the cognitive benefits of bilingualism and the neural mechanisms that underlie cognitive reserve. These insights may have important implications for interventions aimed at promoting healthy aging and improving cognitive function in later life.

2 COGNITIVE RESERVE IN AGING

This chapter provides an overview of cognitive research in aging, drawing upon academic citations to underscore this field's significance and academic foundation. The following sections present definitions and sources of cognitive reserve (2.1) and the role of cognitive reserve in postponing cognitive decline and dementia (2.2). This chapter cites the works of various researchers, including Denise Park, Patricia Reuter-Lorenz, and Yaakov Stern, who have conducted extensive research on cognitive aging across different academic fields.

Cognitive reserve is a term that describes the study of how people's cognitive abilities evolve as they age. The term cognitive reserve pertains to the notion that an individual's cognitive abilities are accumulated over time, which acts as a safeguard against the detrimental effects of aging and illness. As a result, this creates a heightened resilience within the individual, allowing them to access this reserve in later years (STERN, 2022). In a simplified way, it may be comparable to how a financially-minded individual has savings to rely on during trying times. Research has shown that there is no clear link between the extent of brain changes in an individual and the visible effects of those changes. People display varying levels of resilience when it comes to adapting to changes that arise from aging, illness, or brain injury, and studies have demonstrated that two individuals with the same degree of age-related brain changes may perform vastly differently on cognitive tasks (STERN, 2022). The evidence that lifetime experiences such as education, engaging occupation, and participating in stimulating activities - ideally combining leisure activities, learning, and social interactions - help build cognitive reserve comes from studies of large groups of people over long periods that have repeatedly found that these life experiences are associated with a slower rate of cognitive decline in normal aging and a reduced risk of developing Alzheimer’s disease because these experiences help people preserve their cognitive functions better in the face of age or disease-related changes to the brain (STERN, 2012). The mechanisms of how cognitive reserve is developed while people participate in the activities and life experiences cited before are still being determined by research. One probability is that these activities stimulate new, stronger connections in the brain, and the brain networks that underlie specific cognitive functions are more efficient or of higher capacity in some people than others. That said, if the usual brain networks are disrupted, some individuals may be more able to use alternative strategies. (STERN, 2012; BARULLI; STERN, 2013)

Alongside cognitive reserve is brain reserve, and whilst distinct, also intertwined concepts. Brain reserve was defined by Stern *et al.* (2019, p.124) as “a neuroanatomic resource that reflects structural properties of the brain that somehow afford a surplus capacity to maintain cognitive function despite substantial loss of their material substrate.” The idea of brain reserve refers to the amount of neurobiological resources a person has, such as the number of neurons and synapses. This concept suggests that variations in the brain's structural characteristics allow some individuals to handle brain aging and pathology better than others without experiencing clinical or cognitive changes. Brain reserve remains a constant construct at any given time, representing the neurobiological resources available. However, one's life experiences can potentially contribute to brain maintenance and increase brain reserve. (STERN, 2020). The level of cognitive or functional impairments depends on a specific threshold, and people with higher brain reserve may experience a more significant decline before showing signs of impairment. Unlike cognitive reserve, brain reserve is a more passive form of reserve and does not require active adaptation of cognitive or functional processes when faced with insult. On the other hand, cognitive reserve embodies the brain's ability to find alternate paths for task completion when typical pathways are compromised; this concept does not focus on the physical characteristics of the brain, such as size or neuron count, but rather on the adaptability and efficiency of cognitive processes. (STERN *et al.*, 2019; STERN, 2020).

In one of his first papers defining these concepts that have been discussed, Stern (2002, p. 452) defines cognitive reserve as the capacity "to optimize or maximize performance through differential recruitment of brain networks, which perhaps reflects the use of alternative cognitive strategies." As stated before, there can be an augment of the cognitive reserve through mental stimulation, such as education and intellectually challenging activities, and both reserves are essential in enhancing the brain's ability to withstand challenges, which helps explain why some people can delay or reduce the cognitive symptoms of neurological disorders. At last, it is crucial to understand that brain reserve focuses on physical attributes, while cognitive reserve emphasizes cognitive adaptability.

The following chapters provide a more comprehensive understanding of cognitive reserve as we define and specify its sources and discuss its potential to delay the onset of cognitive decline and dementia.

2.1 DEFINING AND SPECIFYING SOURCES OF COGNITIVE RESERVE

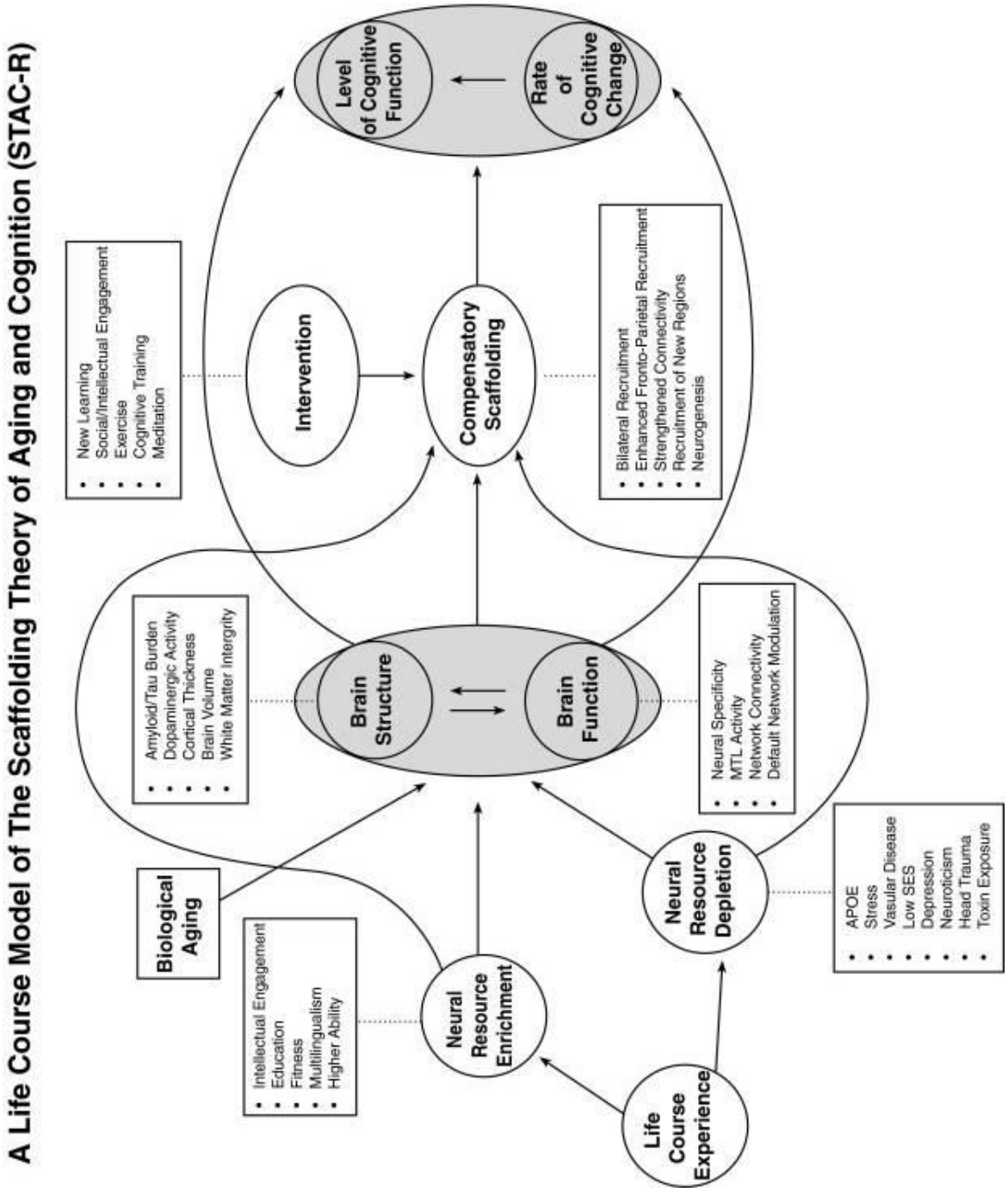
The concept of cognitive reserve suggests that when faced with damage, the brain actively employs its existing cognitive processes or enlisting compensatory mechanisms to cope with damage (STERN, 2002).

The Scaffolding Theory of Aging and Cognition (STAC) was introduced by Reuter-Lorenz and Park (2009) as a theoretical framework for understanding cognitive aging. It integrates findings from both structural and functional neuroimaging to elucidate how the interplay between negative and compensatory neural mechanisms leads to diverse levels of cognitive functioning. STAC portrays the brain as a dynamically adaptive entity that undergoes both positive and negative changes as it ages. Both challenges to neural function and the deterioration of brain health trigger the activation of scaffolding, which diminishes the detrimental impact of brain-related factors on cognitive performance. While typical age-related changes in brain structure and function can prompt compensatory scaffolding, severe deterioration may eventually compromise the brain's capacity for effective compensation. Additionally, their updated model STAC-r (Scaffolding Theory of Aging and Cognition-Revised) exemplified in Figure 1, suggests that specific interventions, such as engaging in exercise, intellectual activities, and new learning, as well as undergoing formal cognitive training, have the potential to enhance neural scaffolding activity. (REUTER-LORENZ; PARK, 2014).

The original STAC model had a drawback where it did not consider external factors that could positively or negatively impact age-related neural reorganization and cognitive response. With the updated STAC-r model, two new components have been added to factor in the combined influence of life experiences, genetic predisposition, and environmental factors that can either enhance or deplete brain resources. The model proposes two pathways by which these beneficial and protective effects can work. The first pathway involves neural enrichment that can directly boost or maintain brain structure and function by promoting efficient connectivity, increasing cortical thickness, synaptic density, and other indicators of brain health. The second pathway, however, is less direct, where the enrichment factors enable enhanced scaffolding despite neural degradation, resulting in continued high cognitive function. In some individuals, aging can still cause deterioration in brain structure and function, even if they possess advantageous factors such as a high level of education. However, having a higher education level can aid in the development of improved compensatory strategies, which can help maintain cognitive function despite neural

degradation. Therefore, older adults who possess high levels of intelligence or education and exhibit normal cognitive function may still experience more severe neural degradation compared to their less educated counterparts. The concept of brain reserve and cognitive reserve has some similarities with the STAC-r model. These shared concepts suggest that both theories can contribute to a better understanding of cognitive aging and potential interventions to preserve cognitive function. (STERN 2012; BARULLI; STERN 2013, REUTER-LORENZ; PARK, 2014)

Figure 1 - Conceptual model of the scaffolding theory of aging and cognition-revised (STAC-R).Source: REUTER-LORENZ; PARK, 2014, p. 360



Extensive research has been conducted on the factors that influence the development of cognitive reserve. Some factors contribute to the creation of cognitive reserve, including Cultural, Emotional, Lifestyle, and Biological factors. Table 1 provides a list and summary of these factors.

Table 1 - Summarized table of the contributing factors to sources of cognitive reserve. Source: The Author

Contributing factors to sources of cognitive reserve			
Cultural Factors	Emotional Factors	Lifestyle Factors	Biological Factors
Education levels: Higher levels of education are associated with greater cognitive reserve (Stern, 2009).	Stress management: Chronic stress can negatively impact the brain, but effective stress management strategies may contribute to cognitive reserve (Lupien et al., 2009).	Physical exercise: Regular physical activity supports brain health and may contribute to cognitive reserve (Stern et al., 2019A).	Genetics: Certain genetic factors, such as the presence of the ApoE ε4 allele, may influence cognitive reserve (Dekhtyar, 2019).
Occupational complexity: Jobs that require complex cognitive tasks can stimulate cognitive reserve (Stern, 2009).	Social connectivity: Strong social networks and emotional support can foster cognitive reserve (Fratiglioni et al., 2004).	Nutrition: A balanced diet rich in essential nutrients can support brain health and potentially enhance cognitive reserve (Morris, 2012).	Brain volume and structure: Individual differences in brain size and structure may be related to cognitive reserve (Stern, 2009).
Bilingualism: Bilingual individuals have been found to possess greater cognitive reserve (Bialystok et al., 2014).	Mental health: Good mental health and effective management of mental health conditions can contribute to cognitive reserve (Opdebeeck et al., 2016).	Cognitive and mental activities: Engaging in mentally stimulating activities, such as reading, puzzles, and games, can promote cognitive reserve (Stern et al., 2003).	Neuroplasticity: The brain's ability to form and reorganize synaptic connections, particularly in response to learning or experience, may contribute to cognitive reserve (Stern, 2012).
Cultural engagement: Participation in cultural activities, such as art and music, may enhance cognitive reserve (Fancourt & Steptoe, 2018).	Resilience: Psychological resilience, the ability to mentally or emotionally cope with a crisis, can contribute to cognitive reserve (Southwick et al., 2014).	Sleep: Quality sleep supports cognitive function and brain health, potentially contributing to cognitive reserve (Casagrande et al., 2022).	Brain-derived neurotrophic factor (BDNF): BDNF, a protein that supports the survival of existing neurons and encourages the growth and differentiation of new neurons and synapses, may impact cognitive reserve (Erickson et al., 2011).

2.2 THE ROLE OF COGNITIVE RESERVE IN POSTPONING COGNITIVE DECLINE AND DEMENTIA

Before developing the discussion on the role of cognitive reserve in postponing cognitive decline and dementia, it is crucial to define what dementia is, as we have defined what cognitive reserve is. According to Voits, DeLuca and Abutalebi (2022, page 1), dementia is:

> "An umbrella term for a set of neurodegenerative diseases [of which Alzheimer's disease (AD) is the most common one] with debilitating symptoms, primarily impairment of memory and other cognitive abilities, eventually leading to loss of autonomy over everyday activities. It is the leading cause of disability for older adults."

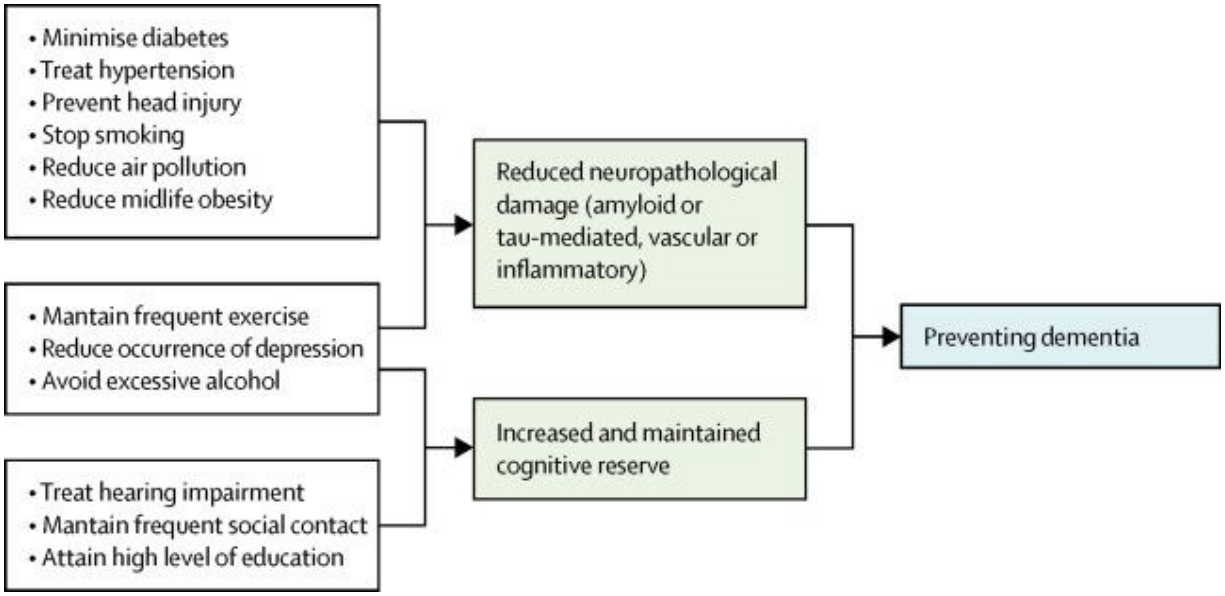
There are currently around 50 million people worldwide who live with dementia, and this number is expected to reach 152 million by 2050. The increase will be particularly significant in low and middle-income countries, where approximately two-thirds of individuals with dementia reside. This condition impacts not only the individuals themselves but also their families and the economy. The estimated global cost of dementia is about US$1 trillion per year (PATTERSON, 2018).

The cognitive reserve hypothesis provides insight into the mechanisms behind cognitive decline and dementia. It posits that how tasks are processed and executed can mitigate the negative consequences of brain damage or age-related alterations. Moreover, variations in cognitive processing and task performance among individuals significantly contribute to cognitive reserve. Scientific literature has well-documented the importance of cognitive reserve in delaying cognitive decline and dementia. According to Stern (2009, p. 2025), cognitive reserve is a theoretical concept that explains why some individuals are more resilient to brain aging, pathology, or injury compared to others and can maintain cognitive function despite these changes. The fundamental concept underlying cognitive reserve is the brain's plasticity and ability to reorganize, compensate for damage, or change in response to new experiences. This flexibility allows the brain to continue performing its tasks even when faced with challenges that come with aging or neurodegenerative diseases.

In a recent report, Livingston *et al.* (2020) reviewed the 2017 Lancet Commission on dementia prevention, intervention, and care to find new evidence for advances that could have a significant impact since their 2017 paper. They conducted thorough reviews of literature and meta-analyses to identify potentially modifiable risk factors for dementia. They summarize this evidence, including systematic reviews and meta-analyses, while discussing its strengths

and limitations. They examined new evidence on dementia risk in low-income and middle-income countries, the factors that increase or decrease the risk of dementia, methods of detecting Alzheimer's disease, how other health conditions impact dementia, and interventions for people affected by dementia. Their study is better exemplified by Figure 2, which provides an overview of different approaches to protect against dementia. These methods aim to maintain or improve cognitive reserve, regardless of any pathological or neuropathological damage. It's important to note that the terminology used to describe the different levels of susceptibility to age- and illness-related changes are not consistent (LIVINGSTON *et al.*, 2020).

Figure 2 - Possible brain mechanisms for enhancing or maintaining cognitive reserve and risk reduction of potentially modifiable risk factors in dementia. Source: LIVINGSTON et al., 2020.



Cognitive reserve is not only associated with a delay in the onset of clinical symptoms of dementia but also with a slower progression of the disease. This means that individuals with a higher cognitive reserve can live longer with the disease without showing severe cognitive impairments. The cognitive reserve hypothesis emphasizes the value of lifelong learning and intellectual stimulation in the prevention or postponement of cognitive decline and dementia. It provides a foundation for interventions that promote mental engagement and cognitive activity, thereby contributing to the mitigation of cognitive decline.

3 BILINGUALISM AND COGNITIVE RESERVE

Depending on the context, the terms "bilingual" and "bilingualism" can have various interpretations. They may refer to the ability to understand and communicate in multiple languages, the delivery of information in two or more languages, the necessity for using two languages, the acknowledgement of two or more languages, and other related concepts. The rapidly evolving dynamics of an interconnected global society have increased the prevalence of bilingualism. Current research estimates that more than half of the world's population is bilingual or plurilingual (GROSJEAN, 2010). As per Grosjean's study, this upsurge is primarily attributed to increased mobility, enhanced global interdependence, and the rise of bilingual education. Therefore, once considered an exception, bilingualism is now becoming a global norm, underscoring the relevance and necessity of research in this area. Defining and understanding the fundamental constructs of bilingualism and individuals is essential to exploring this widespread phenomenon comprehensively. Bilingualism is the ability to use two languages, encompassing a broad spectrum of proficiency levels (BIALYSTOK, 2001). Bilingualism is not strictly confined to individuals with equal proficiency or usage in both languages. Instead, it includes any individual who can function in two languages, regardless of the disparity in skill level between the first and second languages (BAKER, 2011).

With the increased prevalence of bilingualism worldwide, research on the subject has mainly focused on these three fundamental aspects: Age of Acquisition (AoA), proficiency, and language use. The first (AoA) aspect concerns the age at which the second language (or additional language)[1] is acquired and its impact on the proficiency and cognitive processing of the language. While a significant body of research suggests the benefits of early language acquisition, more recent studies highlight that late bilinguals can also achieve comparable proficiency levels (HAKUTA; BIALYSTOK; WILEY, 2003; BIRDSONG, 2006),.The second, proficiency refers to the skill level in both languages, including vocabulary, syntax, and grammar. Even though high proficiency in both languages is not necessary for an individual to be classified as bilingual, it plays a substantial role in determining how language use impacts cognitive processes (ABUTALEBI; CLAHSEN, 2015). Finally, the frequency and context of each language's use are also critical. An individual may possess high proficiency in two languages yet predominantly use only one daily. This aspect profoundly influences the cognitive impact of bilingualism (LUK; BIALYSTOK, 2013). These factors

[1] This monograph does not intend to discuss the different concepts behind the words foreign language, second language or additional language, and these terms may be used interchangeably.

collectively shape the bilingual experience and its cognitive implications. In recent years, a growing body of evidence has indicated that bilingualism may be an influential contributor to cognitive reserve.

In the following sections, we explore the relationship between bilingualism and cognitive reserve, discussing whether or not there is an advantage to being bilingual. Subsequently, we examine the impacts of bilingualism on brain structure and functioning.

3.1 BILINGUALISM AS A SOURCE OF COGNITIVE RESERVE: ARE THERE ANY ADVANTAGES IN BEING BILINGUAL?

In this chapter, we will explore the idea that people who speak multiple languages may have a cognitive advantage that protects them from the adverse effects of aging. To better understand if there is an advantage, we will analyze existing research, review empirical evidence, and consider different theoretical viewpoints. Ultimately, we want to determine whether bilingualism provides a cognitive advantage and how it shapes the human mind.

Throughout our daily lives, the use of language is one of the most continuous and ongoing activities. Psycholinguistic studies have discovered that both languages in a bilingual individual's mind are simultaneously activated. This means that to produce language successfully, one must exercise selective attention and constantly monitor the language being used (KROLL; BOBB; HOSCHINO, 2014). The bilingual language system exhibits clear permeability, as evidenced by both language co-activation and language reorganization. This suggests that bilingualism may have an impact beyond just the linguistic system, potentially restructuring the entire cognitive network (KROLL; BIALYSTOK, 2013). Research points out that bilingualism has the potential to enhance cognitive reserves, as it can provide numerous benefits to the individual. This includes improved problem-solving skills, enhanced memory capacity, and increased attentional control. For that, bilingualism has been linked to a delayed onset of cognitive decline and reduced risk of age-related cognitive impairment (BIALYSTOK, 2021).

The acquisition and maintenance of multiple languages can greatly benefit cognitive functioning and promote healthy brain aging. One of the chief advantages of being bilingual lies in the heightened metalinguistic awareness. Defined as the capability to deliberate and analyze language as an abstract construct (BIALYSTOK, 2001), bilingual individuals exhibit advanced metalinguistic skills. This proficiency primarily stems from the continual switching and translating between two languages, which fosters an intricate understanding of language

as a system (KHARKHURIN, 2010). Further, bilingualism is associated with augmented creativity. The mental flexibility necessitated by the alternation between languages possibly enhances divergent thinking, a critical facet of creativity (ADESOPE *et al*., 2010). These cognitive benefits, accumulated through bilingualism, contribute to building a robust cognitive reserve in bilingual individuals. The cognitive reserve accrued through bilingualism could act as a protective barrier during aging and in the face of neurological disorders, such as Alzheimer's disease (PERANI; ABUTALEBI, 2015).

In a recent paper by Berkes and Bialystok (2022), they explore through a review in several articles that research has shown that bilingual people generally perform better than monolinguals on cognitive tests that measure executive function, though this finding has sparked debate. However, older adults who are bilingual often outperform monolinguals on these tests. One study found that healthy bilingual adults had better mental health scores than monolinguals with similar brain health. Surprisingly, 41% of the monolinguals were diagnosed with mild cognitive impairment (MCI) or Alzheimer's Disease (AD), despite having comparable brain health to the bilingual group. This suggests that being bilingual could be linked to healthier aging. Another finding is that bilingual individuals could handle more brain damage than monolinguals without showing increased signs of cognitive impairment. In addition, research has shown that bilingual individuals tend to show symptoms of dementia about 4.5 years later than monolinguals, even when considering factors like education and immigration status. However, once symptoms of dementia appear, they progress more quickly in bilinguals. This seems contradictory, but the endpoint of disease progression remains the same regardless of language ability. This simply means that bilingual individuals, who have been dealing with more brain damage at the time of symptom onset, decline more quickly when this protective effect is breached. Nevertheless, this could potentially delay the decline and allow for a better quality of life during earlier stages. Overall, the use of two languages seems to offer the best cognitive outcomes despite ongoing brain degeneration (BERKE; BIALYSTOK, 2022).

Some authors question these researches that point out some advantages of being bilingual; one of them is an article by Paap, Johnson and Sawi (2014) that discusses the hypothesis that managing two languages enhances general executive functioning. The study contemplates the complexities of bilingual studies by considering various influencing factors. These encompass the limitations imposed by reduced sample sizes, the role of the age of language acquisition, the way proficiency is measured — contrasting self-assessment and standardized instrument — and the distinctive cognitive differences in individuals such as

memory, executive functions, and attention. Another critical aspect concerns bilingual individuals who are non-literate in their second language (L2), a common phenomenon in immigrant languages where individuals excel in speaking and oral comprehension but lack reading and writing skills. Furthermore, the subjects' socioeconomic status and education level are considered alongside the quality and quantity of reading, either individual or shared with parents. The authors believe these factors impact vocabulary acquisition and overall language comprehension considerably. The methodological aspects related to the tasks in the research are equally intricate. The tasks often fail to distinguish between the analysis of verbal and non-verbal items and do not segregate components of executive functions such as inhibition and mental flexibility. In addition, there is an inherent need to isolate the study of different types of attention — sustained and selective, among others — frequently merged in current research methodologies. These components are vital to methodological examination to refine the understanding of bilingualism and its potential cognitive implications. (PAAP; JOHNSON; SAWI, 2014)

Another article by Paap, Johnson, and Sawi (2015) casts a critical lens over the widely held belief that the ability to manage two languages enhances general executive functioning. Their comprehensive analysis revealed that most investigations into bilingual advantages—specifically more than 80% of tests conducted after 2011—yielded inconclusive or null results, putting the concept of cognitive advantages into question. Furthermore, when studies did demonstrate statistically significant bilingual advantages, they were often characterized by notably small sample sizes, raising concerns about the generalizability of such findings. The authors further questioned whether some positive findings appropriately considered various demographic factors, implying that unaccounted variables could potentially influence results. This concern was further highlighted by the challenges encountered in attempts to replicate previous findings, pointing towards a need for more rigorous study design and analysis in this field. In the context of neuroimaging studies, they identified a mismatch between neural and behavioral differences, implying that neural variations do not always manifest as observable behaviors. The authors arrived at a measured conclusion that the magnitude of the effects indicating bilingual advantages if they do exist, is likely to be observed only sporadically and under specific, constrained circumstances. This conclusion emphasizes the necessity for a nuanced understanding of the impact of bilingualism on cognitive functions, factoring in many variables beyond language proficiency alone. (PAAP; JOHNSON; SAWI, 2015)

Although there are varying perspectives on the matter, it is important to recognize that bilingualism can serve as a valuable cognitive reserve. This has important implications for

cognitive neuroscience and overall health outcomes. By fully understanding the benefits of bilingualism as a cognitive asset, we can develop better strategies for promoting cognitive resilience and preventive health measures.

3.2 BILINGUALISM AND ITS ROLE IN BRAIN STRUCTURE AND FUNCTIONING

According to Bialystok (2021), bilingualism has a significant impact on the structure and function of the brain. Being able to speak two languages improves communication skills and causes fundamental changes within the brain itself. This section, focuses on how bilingualism shapes our neural architecture and cognitive processes, especially in older adults. We will examine evidence that mastering two languages can enhance cognitive reserve, and neural plasticity, and potentially help prevent age-related cognitive decline as we review articles by Bialystok, Voits, De Luca, and Abutalebi, among others.

Being able to speak two languages can positively impact a person's cognitive abilities and brain function. Moreover, it can affect the functional aspects of the brain, specifically when it comes to executive control and attention. There have been numerous studies conducted that have shown the positive effects of bilingualism on the physical structure of the brain that can lead to structural neuroplasticity, the ability of the brain to adapt and restructure itself regarding physical aspects (LI; LEGAULT; LITCOFSKY, 2014; BIALYSTOK, 2017). Regarding the brain’s structure, one recent and promising study is the one conducted by DeLuca and Voits (2022) that analyzed the impact throughout an individual's life of bilingualism on the decline of white matter (WM) integrity, defined by the authors as "a crucial element in the neural architecture that ensures communication between different brain regions." Their goal was to investigate how being bilingual affects the path of white matter decline during the process of healthy aging. Secondly, investigate how engaging in bilingual experiences can potentially improve the trajectory of WM integrity throughout adulthood, analyzing two commonly utilized measures of WM integrity, which include fractional anisotropy and mean diffusivity. These measures provide insights into the patterns of WM microstructure and the degree of myelination in the brain tissue. Reductions of White Matter integrity are represented as increases in Mean diffusivity values and lowers in FA values. For participants, a total of 78 people, the majority being females with an average age of 51.6, participated in the study. The requirements to participate were being right-handed, having no speech and language issues, and being able to undergo an MRI scan. Participants were from the UK and included both bilinguals (people speaking English and at least one more

language) and monolinguals (English speakers with little or no knowledge of another language). The age range of the bilingual group was broad, while the monolingual group mostly included middle-aged and older individuals. All participants filled out a questionnaire called the Language and Social Background Questionnaire (LSBQ), which helped them understand their language exposure and use in different settings. It provided a score indicating the level of bilingual engagement. Higher scores represented more interaction with both languages, and lower scores indicated less interaction. The study also considered the education level of the participants by scoring them on a scale from 1 (no secondary education) to 5 (graduate or professional-level degree), with each number reflecting the highest education level they achieved. Lastly, a subgroup of participants, particularly those who were 48 years old and above (with one exception), also took a cognitive test called the Addenbrookes Cognitive Examination (ACE-III). This test measures attention, memory, fluency, language, and visuospatial processing abilities. A score of at least 82 out of 100 on this test indicates good cognitive health. For image data acquisition, participants underwent an MRI scanning and a diffusion tensor imaging scan (DTI). Their research suggested a less significant decline in white matter integrity among bilinguals than monolinguals. An analysis was conducted on the effects of age on the trajectory of white matter integrity and the potential moderating role of bilingualism. The study found that the monolingual group showed a significant age effect in their white matter integrity decline, while the bilingual group did not. This suggests that the monolingual cohort experienced a faster decline. Also, an interaction between age and degree of bilingual engagement in white matter integrity was also observed. It was found that individuals who consistently use two languages throughout their lifetime experience a slower decline in the health of their white matter. In other words, being bilingual and regularly using both languages can positively impact the rate at which age-related decline in white matter occurs (DELUCA; VOITS, 2022).

The human brain has an impressive capability of acquiring and utilizing multiple languages. Scientific research indicates that the brain regions involved in both languages are the same for individuals who are proficient in bilingualism (ABUTALEBI; GREEN, 2007). Previous studies have indicated that the way the brain functions when processing the first language can have an impact on how it functions when processing a second language. Bilingual individuals may either use the same functional network as their first language to process the second language or rely on different brain regions to handle the specific requirements of the second language (ABUTALEBI; GREEN, 2007). However, the effects of

L2 acquisition on the functional network of L1 processing in bilingual individuals remain uncertain.

To shed light on this topic, Zou *et al* (2012) conducted an examination, revealing that in bimodal bilinguals - individuals who use both spoken and sign language - the functional network supporting L1 production (spoken language) has been restructured to include the network supporting L2 production (sign language). The use of functional magnetic resonance imaging (fMRI) and a picture naming task allowed them to discover that during L1 production, bilingual speakers exhibit greater utilization of the right supramarginal gyrus (RSMG), the right temporal gyrus (RSTG), and the right superior occipital gyrus (RSOG) compared to monolingual speakers. Their findings indicate that L1 production in bimodal bilinguals involves an interplay between L1 and L2, thereby supporting the notion that learning a second language alters the functional brain network of the first language. The functional brain network of a bilingual's first language (L1) plays a crucial role in shaping that of their second language (L2). However, how L2 acquisition changes the functional network of L1 processing in bilinguals needs to be clarified (ZOU *et al*, 2012).

In summary, being bilingual has a profound impact on the structure and function of the brain. It creates a complex interaction between the neural elements of two languages, resulting in significant neuroplastic changes. These changes reshape existing networks, activate more parts of the brain, and improve functional connectivity. Learning and using a second language can even change the neural architecture that supports the first language, as demonstrated in people who speak two languages with different modalities. Studying bilingualism helps us understand the complexity of human language and the fantastic adaptability and flexibility of the brain. It provides a unique perspective into the workings of our cognitive processes.

In the following chapters, we will discuss and provide final thoughts on all the topics covered in this paper.

4 DISCUSSION

Following our research questions (1) How does bilingualism interact with cognitive reserve in aging? (2) What are the behavioral and brain correlates of bilingualism as a source of cognitive reserve, this monograph delves into the ongoing debate surrounding the cognitive advantages of bilingualism, examining a range of studies that shed light on the complex relationship between bilingualism and cognitive reserve, especially when it comes to the aging process.

Regarding the first question “How does bilingualism interact with cognitive reserve in aging?” we were able to present studies that shed light into the fact that bilingualism may be linked to healthier aging. The study by Berke and Bialystok (2022) that is a very comprehensive systematic review, they present to us studies that suggest that bilingual individuals tend to perform better than monolinguals on cognitive tests that measure executive function, and older bilingual adults often outperform monolinguals as well. Therefore, being bilingual may also be linked to better mental health scores, and the ability to handle more brain damage without showing signs of cognitive impairment. Notably, in this paper they present that 41% of the monolinguals in the study exhibited symptoms of mild cognitive impairment (MCI) or Alzheimer's Disease (AD), despite having equal brain health as the bilingual group. However, once symptoms of dementia appear, bilingual individuals may decline more quickly than monolinguals. Overall, using two languages appears to offer the best cognitive outcomes despite ongoing brain degeneration (BERKE; BIALYSTOK, 2022). These results suggest that bilingualism may be an important source for cognitive reserve and help individuals go through the implications of the aging process.

We also presented the counterpoints, those who question the validity of these findings, and we acknowledge the skepticism surrounding the topic, as we presented that some researchers like Paap, Johnson and Sawi (2014) who argue that bilingual studies are complex and influenced by various factors. These include sample size, age of language acquisition, proficiency measurement, cognitive differences, non-literacy in L2, socioeconomic status, education level, and reading quality and quantity. Methodological aspects are also intricate, with tasks often failing to distinguish between verbal and non-verbal items and not segregating executive function components. Attention types need to be isolated to refine the understanding of bilingualism and its cognitive implications. These components are critical to refining the understanding of bilingualism and its cognitive implications. Another paper by the same authors argue that studies illustrating the advantages of bilingualism often have

small sample sizes and do not sufficiently consider demographic factors, indicating that unaccounted variables could potentially impact results, raising concerns about the generalizability of such findings (PAAP; JOHNSON; SAWI, 2015).

Regardless of the counterpoints presented about how bilingualism interacts with cognitive reserve in aging, it is essential to understand the importance of bilingualism when it comes to a healthier aging process, not only because learning a new language, engaging in social activities - like a class of a language course – have been pointed as sources of cognitive reserve, being bilingual opens doors to different cultural and social experiences that may enhance our cognition and therefore provide us with a healthier aging.

About the second question “What are the behavioral and brain correlates of bilingualism as a source of cognitive reserve?” we presented studies about the impact of bilingualism on the structure and function of the brain; an article by Bialystok (2021), pointed that bilingualism has a significant impact on the structure and function of the brain, and that being able to speak two languages improves communication skills and causes fundamental changes within the brain itself. Bilingualism has been found to reshape existing networks, activate more parts of the brain, and improve functional connectivity. A study conducted by DeLuca and Voits (2022) analyzed the impact of bilingualism on the decline of white matter integrity in an individual's brain throughout their life. The study found that bilinguals had a less significant decline in white matter integrity than monolinguals. The study also found that individuals who consistently use two languages throughout their lifetime experience a slower decline in the health of their white matter. The study measured white matter integrity using fractional anisotropy and mean diffusivity. The study included 78 participants, mostly females with an average age of 51.6, who filled out a questionnaire called the Language and Social Background Questionnaire and underwent an MRI scan and a diffusion tensor imaging scan (DTI). Monolinguals experienced a faster decline in white matter integrity with age than bilinguals. A study by Zou *et al.* showed that bimodal bilinguals - individuals who use both spoken and sign language - have a restructured functional network supporting L1 production (spoken language) to include the network supporting L2 production (sign language). During L1 production, bilingual speakers exhibit greater utilization of specific brain areas compared to monolingual speakers. Learning a second language alters the functional brain network of the first language, and the functional brain network of a bilingual's first language plays a crucial role in shaping that of their second language.

These findings suggest that bilingualism not only enhances cognitive reserve and neural plasticity but also potentially helps prevent age-related cognitive decline. Although there are

duality of some authors about the impacts of bilingualism on cognitive reserve, it is important to acknowledge that as a society, we live in a multilingual world, that connects not only through the advances of technology and the internet but also through the powerful connections that only language can provide. An additional language impacts someone's life completely, once it allows them to expand cultural and societal barriers, amplifying their worldview. Therefore, it seems reasonable to say that bilingualism can serve as a valuable source of cognitive reserve, and its implications should be considered for further studies regarding cognitive neuroscience and the aging process because the increase in life expectancy is not just a trend; it is our undeniable reality.

DeLuca, Voits, and Abutalebi (2022) addressed the obstacles interfering with recognizing bilingualism as a valuable factor in all research fields. It also emphasized the advantages of considering language experiences as a significant aspect of various studies. Language is the core of our communication; as humans, we seek connection, and language makes it possible to build bridges with different individuals and connect them. When speaking of a globalized world, one cannot dissociate from the fact that nowadays it is almost impossible not to be impacted by a different language in one's daily life; there are words and sentences from different languages all over the city, on advertising billboards, restaurants facades, and if we consider the internet, the online world, this impact only grows more significant, as we have access to products from various areas of the world such as movies, music, series, among other cultural products.

Considering the growth of the aging population and, therefore, the increase of their digital and online presence, it is crucial to study the impacts of bilingualism on the aging process. Possibly, twenty years from now, there will be an increased number of bilingual older adults compared to the present day. Therefore, it is vital to understand – through multidisciplinary scientifical research - if there is an advantage to being bilingual during the aging process. Then, research must be conducted on what might impact and be a source of cognitive reserve - whether it is bilingualism or not – so that light can be shed on future outcome measures that governments should adopt to take care of the increasing population of older adults, focusing on prevention and not only treatments for cognitive decline and dementia.

5 FINAL CONSIDERATIONS

The reason why I decided to investigate the impacts of bilingualism on cognitive reserve in aging is that since 2020, when I joined the group of studies in neurolinguistics and psycholinguistics (GENP), we have discussed several articles regarding bilingualism, the aging process, among others and it always fascinated me how powerful language is; a construct that is inherent to all humans, no matter its form. And that is why I decided to study second language acquisition and teaching during my graduate studies.

The aims of this monograph were (1) To verify how bilingualism impacts cognitive performance in aging, regarding linguistic and other cognitive constructs (memory, executive functions, attention), (2) To verify how bilingualism impacts the aging brain structurally and functionally. As presented in this paper, some results are inconclusive regarding measures of cognitive reserve and how bilingualism impacts cognitive performance in the aging brain. Nevertheless, the positive effects of bilingualism on brain structure and functioning seem undeniable. Regarding the limitations of this paper, it is important to address that some other relevant studies on the topics covered here may not have been included, so this paper does not intend to limit the discussion. However, some of the most prominent researchers on bilingualism, aging, and cognitive reserve have been highlighted. As for further research, it would be interesting to study issues like how bilingualism could be used as a means of brain, linguistic, and cognitive stimulation as a treatment to cope with already installed mild cognitive decline or Alzheimer's disease, as well as in other neurodegenerative illnesses such as in the three variants of primary progressive aphasia (PPA), or still after a stroke.

In conclusion, as our world continues to embrace the rhythm of globalization, bilingualism has never been more prevalent or necessary. The beauty of bilingualism lies not only in the possibility of understanding and appreciating different cultures but also in its powerful potential to enhance cognitive development. Given its various benefits, governments must invest in policies that uphold and support the sustainability of languages, including those of indigenous and immigrant communities, as seen in the Brazilian and other countries contexts. Moreover, policies should aim to fortify the teaching and learning of additional languages by applying valuable insights from neuroscience. As the famous psycholinguist, Frank Smith said, "One language sets you in a corridor for life. Two languages open every door along the way."

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