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The Impact of Bilingualism on Cognitive Reserve as a Protectant Against Cognitive Decline

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ABSTRACT

Cognitive decline exists on a spectrum, ranging from mild cognitive impairment to dementia. These two diagnoses encompass a group of symptoms rooted in the progressive decline of cognitive function, impairing aspects like memory, decision-making, language use, and locomotion. This review centers upon the premise of cognitive reserve, an intangible measure of the brain's resilience and capacity to compensate for damage, and its relationship with the preservation of cognitive function later in life. Bilingualism constitutes one of many contributing factors to a higher cognitive reserve; however, this term fails to reflect the unique linguistic profile intrinsic to every individual—including whether a second language was acquired during childhood or later in life. Therefore, a distinction between "acquired" and "lifelong" bilingualism is made. Through the analysis of task-based and neuroimaging data, this review article elucidates the impact both forms of bilingualism have on cognitive reserve as a protectant against cognitive decline, revealing that resultant neuroprotective advantage is most salient when both languages are used regularly, in diverse environments, and in an active manner. These practices are observed in both acquired and lifelong bilinguals to varying degrees, which are contextualized and explored in detail within the review.

Introduction

Dementia is a broad term referring to a variety of interrelated symptoms as a result of a progressive decline in cognitive function, otherwise known as cognitive decline.[1] Often rooted in the onset of a particular neurodegenerative disease, common symptoms of dementia include impaired memory, decision-making, use of language, and locomotion.[1] Despite over $3.7 billion being dedicated annually to research on Alzheimer's disease, the most prevalent neurodegenerative disease and cause of dementia,[2] researchers have yet to contrive a concrete cure. This is where the concept of cognitive reserve acquires particular pertinence.

Cognitive reserve is defined as an intangible measure of the brain's capacity to compensate for damage. In essence, the higher one's cognitive reserve, the more resilient their brain will be against loss or damage to neural cells and networks.[3] This is significant in the context of cognitive decline as it allows regions of the brain affected by the pathophysiological manifestations of neurodegeneration — for instance, neurofibrillary tangles caused by the abnormal buildup of tau protein — to be compensated for through the use of fewer or alternate neural networks.[4] Several factors influence cognitive reserve, including education, occupation, social and leisurely habits, as well as language use (i.e. mono- vs. multilingualism).[5] This review article will focus primarily on the impact of bilingualism on cognitive reserve.

It must be taken into account, however, that "bilingualism" is a vague term that fails to encapsulate the true nuance that accompanies the unique linguistic profile of every individual. This includes the consideration of factors like level of proficiency, age of acquisition, the environment(s) in which each language is used, and frequency of use. Therefore, it is important to make a distinction between "lifelong" and "acquired" bilingualism. Acquired bilingualism can be defined as the successful acquisition of proficiency in an additional

language in or beyond adolescence, whereas lifelong bilingualism refers to the quality of speaking two languages from early childhood,[6] and thus being raised in an environment where more than one language is regularly used.

Through the analysis of neuroimaging data, this review article will elucidate the effects of acquired vs lifelong bilingualism on cognitive reserve as a protectant against the onset of dementia symptoms, and thereby ascertain whether one type of bilingualism elicits more inherent advantage than the other.

Cognitive Reserve: How it works and what it can do

Cognitive reserve refers to the ability of the brain to cope with damage by employing available brain tissue more efficiently to compensate for any loss.[7] This is a "dynamic" process, wherein damage to one region of the brain can be accommodated by other regions adapting to carry out its functions in its place, or requiring lower neural activation altogether to achieve the same functional outcome.[8] This phenomenon is known as neural "efficiency."[9]

There is an inversely proportional relationship between neural efficiency and cerebral metabolism.[9] Cerebral metabolism is a measure of the net energy consumed by the brain in synaptic transmission — the transferral of electrochemical signals from one neuron to another — over a given period of time.[10] Because of this relationship, individuals with higher cognitive reserve tend to demonstrate more significant hypometabolism in the brain, and thus greater efficiency.[11] This finding indicates that less energy is utilized for net synaptic transmission in individuals with higher cognitive reserve. Fewer neurons are therefore required to be "activated" to achieve the same functional outcome.

While cognitive reserve does not slow the rate of cerebral atrophy in neurodegeneration, it allows the brain to function as normal in spite of it. This is particularly evident in the scope of simple, everyday tasks — for instance, simple arithmetic or short-term memory recall — rather than more complex tasks (e.g., multitasking or complex motor coordination).[12]

It has been well-documented in the literature that a higher cognitive reserve works to delay the onset of dementia symptoms. In a longitudinal study conducted by Soldan and colleagues (2017), dementia patients with similar baseline pathology who had a level of cognitive reserve above the median of the sample group experienced a mean delay of seven years in the presentation of symptoms relative to those with levels of reserve below the median.[13] This shows that a higher cognitive reserve is associated with a later onset of dementia symptoms, despite similar disease pathology.

It must be noted, however, that upon the initial presentation of dementia symptoms, patients with higher cognitive reserve tend to decline at a much faster rate than those with lower reserve.[7] Figure 1 provides a visual representation of this phenomenon. This can be explained through the implication that loss of cerebral tissue does not correlate, neither immediately nor directly, with externally perceived cognitive decline. In patients with higher cognitive reserve, the presentation of initial symptoms is indicative of damage to such an extent that it can no longer be compensated for by existing neural tissue.[14]

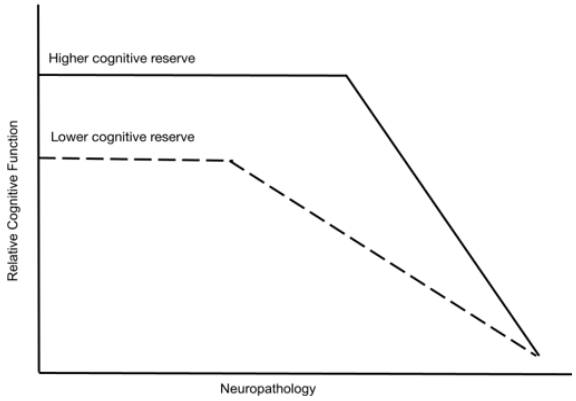

Figure 1. The relationship between neuropathology and relative cognitive function in dementia patients with lower and higher cognitive reserve. Demonstrates that individuals with higher cognitive reserve are able to withstand a greater extent of neuropathology relative to individuals with lower reserve, before experiencing a decline in cognitive function. However, upon the presentation of initial symptoms, individuals with higher reserve experience a decline in cognitive function at a faster rate. Adapted from Stern et al. (2012). "Cognitive reserve in aging and Alzheimer's disease."

The Contribution of Bilingualism to Cognitive Reserve

A positron emission tomography (PET) study conducted by Perani and colleagues (2017) investigated changes in the cerebral metabolism of bilingual and monolingual patients with probable Alzheimer's disease. Researchers measured cerebral metabolism while patients completed simple tasks involving attention, language production, and short and long term verbal and visuospatial memory.9On average, the bilingual patients demonstrated more severe hypometabolism relative to their monolingual counterparts during the completion of the tasks (See Fig. 1 in Perani et al., 2017 for a visual).[9] Lower rates of metabolic activity were observed especially in the left hemisphere, which is associated with abstract thinking, speech, and language production.[15] Increased connectivity was also observed in the frontoparietal network,[9] which is primarily associated with executive function — the process by which individuals are able to divert attention between multiple tasks simultaneously.[16]

These findings show that the bilingual patients required less net metabolic expenditure, and thus less neural activation, during the completion of the tasks. They additionally maintained similar or greater attainment to their monolingual counterparts. In fact, the bilingual patients were observed to outperform the monolingual patients in the tasks measuring attention, verbal, and visuospatial memory, whereas attainment in language production was similar in both groups.[9]

It should be noted, however, that healthy bilinguals tend to exhibit increased difficulty in completing language-related tasks than monolinguals.[6] This is due to a decreased accessibility of words in both languages, rooted in the fact that bilinguals use each word in both languages less frequently than monolinguals do.[6] As such, the fact that the bilingual patients attained similar results to their monolingual counterparts, paired with the increased hypometabolism in the left hemisphere, could suggest the surmounting of this known impediment.

Ultimately, this study exhibits the presence of greater cerebral hypometabolism in bilingual patients,[9] an indicator of increased neural efficiency. This, paired with the similar or increased attainment in bilinguals compared to monolinguals despite similar neuropathology, is representative of the greater levels of cognitive reserve intrinsic to bilingual individuals as well as the neuroprotective advantage they elicit — especially in the scope of simple, quotidian tasks.

The Effects of Lifelong Vs. Acquired Bilingualism

It is important to note that the contributions of bilingualism to cognitive reserve are most salient when both languages are spoken frequently, proficiently, and from an early age (i.e., in lifelong bilinguals). This is because native-like proficiency is typically obtained when another language is acquired during early childhood.[17] Lifelong proficiency in more than one language has additionally been linked to an increased volume of cerebral gray matter, structural integrity of white matter, and cortical thickness.[18]

One notable exception involves heritage speakers, or individuals who acquire another language during childhood solely as a result of exposure in a household setting.[19] Heritage speakers may possess a native-like ability to comprehend the language, but not an active command of the production of text — whether it be written or oral.[20] Although classified as "lifelong" multilinguals, heritage speakers may possess lesser proficiency in the second language as a consequence of not speaking and/or being exposed to it on a regular basis outside of a household setting.

Bilingualism additionally exists on a spectrum, ranging from passive to active bilingualism. Passive bilingualism is defined as the ability to comprehend a language but not speak it proficiently, whereas active bilingualism is defined as the ability to both comprehend and communicate in a language, whether it be through speech or writing. Heritage speakers are most often passive or passive-leaning bilinguals.[21]

A study by Calabria and colleagues (2020) investigated the neuroprotective advantages of bilingualism in Barcelona, where both Spanish and Catalan are spoken to varying degrees of proficiency. They conducted this study using a bilingualism gradient ranging from passive to active bilingualism.[22] Years of exposure, age of acquisition, proficiency in speech reception and production, and frequency of usage of the second language were used as proxies to ascertain the degree of bilingualism of every individual.[22]

Participants were separated into three groups: a control group of healthy individuals, patients with mild cognitive impairment (MCI) — an early stage of cognitive decline where preliminary symptoms begin to manifest, and patients with Alzheimer's disease. All participants completed three tasks involving executive control: a flanker task, spatial Stroop task, and a task switching task, as well as two tasks involving episodic memory retention: an n-back task, and facial recognition task.[22]

Across the MCI and Alzheimer's groups, it was found that individuals with higher degrees of active bilingualism were diagnosed with mild cognitive impairment, on average, two years later than their passive bilingual counterparts.[22] These individuals also performed better in the tasks involving both executive function and episodic memory altogether.[22] These findings suggest that a second language, whether it be lifelong or acquired, must be used and manipulated on a regular basis — and in a diverse range of environments — for the individual to reap the highest degree of neuroprotective advantage.

Limitations

It should be prefaced that languages within the same language family tend to have a high lexical similarity, a percentage used to quantify how similar the complete word sets of two different languages are. Catalan and Spanish, the two languages utilized in the study by Calabria and colleagues (2020), are both Romance languages and have a lexical similarity of 85%.[24] On the other hand, German and Italian, the languages utilized in the study by Perani and colleagues (2017), are in different language families and have an unequivocally lower, yet officially undefined lexical similarity. The results of these individual studies cannot, therefore, be generalized across all bilinguals.

Languages with a higher lexical similarity are thought to be more conducive to task switching, a central component of executive function.[25] However, due to their similarity in terms of grammatical structure and vocabulary, less executive control may be required altogether to switch between and use both languages regularly.

This is because the first language may be used as a basis for comprehension, speech, and/or textual production in the other.[26] This may result in less contribution to cognitive reserve relative to that of the regular use of two lexically dissimilar languages.

Moreover, cognitive reserve itself is an unquantifiable measure that is influenced by multiple factors independent of bilingualism, including education, occupation, and social and leisurely habits.[5] As no individual will share the same circumstances or opportunities—both within and outside of the scope of language—the exact, precise extent of bilingualism's impact on cognitive reserve is unknown.

In acknowledgement of these limitations, future research should be conducted on the quantification of cognitive reserve via universally defined and empirical proxies, as well as the effect that the lexical similarity between the two languages bilinguals speak has on cognitive reserve. Such clarity will allow researchers to ascertain whether there is a significant difference between results obtained from bilinguals whose language profiles fall within and between different language families.

Conclusion

Ultimately, the contribution of bilingualism to cognitive reserve has been evidenced to be most salient in individuals who use both languages in an active manner — regardless of their status as acquired or lifelong bilinguals, though more evident in those who use both languages regularly in a diverse array of environments and less in passive bilinguals and heritage speakers. This is an associative byproduct of the influence active bilingualism has on cognitive reserve.

Cognitive reserve has been observed to manifest itself in neuroimaging data through increased cerebral hypometabolism, and thus the necessity for less neural activation in the completion of the same tasks relative to individuals with less reserve. This demonstrates the compensatory mechanism cognitive reserve has, and therefore the manners in which it can be applied in the context of atrophy or damage to certain regions of the brain as a result of neurodegeneration underpinning cognitive decline. It can thus be ascertained that a higher cognitive reserve, rooted in active bilingualism, contributes to the delayed onset of symptoms of age-related cognitive decline.

This paper, having centered itself on bilingualism, also brings into question how the cognitive reserve of individuals who speak more than two languages may compare — in other words, whether cognitive reserve acts in accordance with quantity over quality, or vice versa.

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