Impacts of Lifelong Bilingualism on Neurodegenerative Diseases

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Abstract

Lifelong bilingualism is the regular use of two languages throughout one's daily life. Constantly switching between languages requires more control over word selection and the ability to resolve interference from the language not in use (Abutalebi & Green, 2016). Because bilinguals face these conflicts on a regular basis more often than monolinguals, there has been evidence of structural changes and increased connectivity from overuse of certain areas and networks of the brain associated with carrying out these executive control tasks. This article aims to provide insight into how bilingualism and reserve works together, and how that relationship can manifest improvement in cognitive functioning in individuals with neurodegenerative diseases.

Introduction

According to the 2021 census, 22% of the U.S. population who are older than 5 years speak another language other than English (U.S. Census Bureau, n.d.). Researchers have found that Alzheimer's disease (AD) is delayed by 4-5 years in lifelong bilinguals when compared to their monolingual counterparts (Bialystok et al., 2007; Craik et al., 2010). The exact mechanisms underlying this phenomenon are not quite known, but many interpretations of various observational results have indicated that because the bilingual experience involves constant cognitive conflict between two languages, there is a strengthening in associated networks as well as structural changes in the brain that ultimately contribute to cognitive and brain reserve. Since bilinguals face these conflicts much more often than monolinguals do, they consequently have larger reserves that serve as a neuroprotective factor against neurodegeneration or even the normal course of cognitive decline that comes with aging.

Reserve is a hypothetical construct used to explain how some individuals who have suffered brain damage maintain similar cognitive and functional ability to those with healthy undamaged brains. The amount of reserve an individual has determines the amount of damage the brain can tolerate without deterioration in functioning. Increased brain reserve allows for 'damage' to accumulate without significantly affecting cognitive ability, which may explain why bilingual individuals show less cognitive decline than monolinguals, even when their brains exhibit greater levels of deterioration (Gold, 2015; Bialystok et al., 2007; Sala et al., 2021). This then leads to the question of whether bilingualism may also help protect against expression of clinical symptoms in other neurodegenerative disorders such as Parkinson's disease (PD) and multiple sclerosis (MS). According to one literature review, this is possible as there is insufficient evidence to conclude otherwise (Voits et al., 2020).

The incidence of Alzheimer's disease in the U.S. in 2050 is projected to double, according to Alzheimer's Association (Alzheimer's Association, 2023). Therefore, it is vital to thoroughly investigate the link between neurodegeneration and the bilingual experience, which may reduce neurodegenerative disease prevalence (Bialystok et al., 2007) and improve overall quality of life. But to understand how bilingualism can delay clinical expression of neurodegenerative diseases, we must first understand the concept of reserve and the protective role it plays.

Reserve

Reserve explains how some people with brain damage demonstrate a similar level of cognitive ability to people with non-damaged brains. One case showing this is a study done by Katzman et al. where 10 patients with AD performed as well as matched controls did on cognitive tests. They also found that these patients had larger brain weights and more neurons than the controls to maintain cognitive and functional ability through mechanisms of reserve (Katzman et al., 1988). There are two types of reserve models: active and passive. These models differ in the way they are defined and may lead to different interpretations of results, but in the case of bilingualism, both are applicable.

Active Model - Cognitive Reserve and Compensation

The active model currently involves two subtypes of reserve: cognitive reserve and compensation. Cognitive reserve (CR) refers to the way an individual approaches a task in terms of the networks and resources the brain uses in the moment, hence "active." It is also active in the sense that it depends on neural activity, experiences, and exposures that the person experiences in their lifetime (Barulli & Stern, 2013). Therefore, people with higher cognitive reserve can carry out cognitive tasks in a more efficient manner (Stern, 2002). The main proxies that have been the most studied are education, occupation complexity, IQ, and, a more recently introduced yet prevalent one, bilingualism. In terms of these proxies,

higher education levels, cognitive demand by an occupation, and IQ are associated with greater levels of cognitive reserve. An example of cognitive reserve coming into play includes a study done by Poletti et al. where they found more educated patients with Parkinson's disease (mild cognitive impairment (PD-MCI)) had a slower progression towards Parkinson's disease dementia (PDD) than those who were less educated (Poletti et al., 2011). A different study by Thorvaldsson et al. investigated effects of IQ in terminal decline (TD) on motor speed, perceptual speed, spatial ability, and verbal ability in the elderly population of Gothenburg, Sweden. TD is the acceleration of cognitive decline a person experiences in their final years before death. They first measured the IQ of the participants using a simplified version of the Raven Standard Progressive Matrix called the Raven Coloured Progressive Matrix, which was more suitable for older participants. Results show that those with higher IQ tended to express later onset of cognitive declines in the variables of interest than those with lower IQ, which is in line with the cognitive reserve hypothesis (Thorvaldsson et al., 2017).

Stern describes cognitive reserve as arising from two ways of using brain networks: increased efficiency in using a network of interest and the ability to recruit alternative networks to carry out increasingly demanding tasks (Stern, 2002). According to referenced studies, the normal response to a more difficult task is to use the current brain network more actively and/or to recruit additional networks to help (Stern, 2002). Between two individuals with different levels of cognitive reserve, the person with a higher amount will recruit the same amount of neuronal activity on a difficult task as the individual with a lesser amount on an easier task. For the ability to recruit alternative networks, Stern writes that having a higher cognitive reserve enables an individual to recruit a larger array of networks to carry out a difficult task (Stern, 2002). Compensation is very similar to cognitive reserve, but it is referred to as such in the context of brain injury or brain damage (Barulli & Stern, 2013; Stern, 2002). When someone suffers brain damage that affects the normal brain network they use for a certain task, they are forced to use an alternative method to complete the same type of task. Their brain must "compensate" for the impaired or lost network. One of the proposed neurological bases for cognitive reserve is known as neural reserve, which encompasses the networks that are used during task processing (Barulli & Stern, 2013).

Passive Model - Brain Reserve (Threshold Model)

The passive model, or threshold model, is solely based on the brain's anatomical structure. This would include brain size or weight, the number of neurons it has, the number of synapses, gray matter volume, and so on. Compared to cognitive reserve, this model is much more objective as it relies on a strict structural component that determines what is called brain reserve capacity (BRC). The theory is that every person has a certain predetermined level of BRC based on their brain structure, hence why this model is "passive."

If a person suffers through an insult to the brain, the functional impairment is expressed in the amount of damage that has exceeded the amount of BRC. In other words, there is a "threshold" that must be surpassed for brain damage to express its effect on cognitive function (Barulli & Stern, 2013; Stern, 2002). This is not to say that BRC is predetermined at birth. It is based on brain structure at the time insult was received, which can account for any accumulated structural changes.

Lifelong Bilingualism and Reserve

Bilingualism can be defined as a gradient in terms of the proficiency of the second language (L2), from elementary to near-native. In this paper, bilingualism is defined as having near-native proficiency of L2 from a young age, unless specified otherwise. Bilingualism as a proxy for cognitive reserve has more recently gained prevalence in the last couple decades compared to other proxies such as occupation (Bialystok et al., 2007, Gold, 2015; Subramaniapillai et al., 2021 (review)).

This includes selecting the target language according to context, selecting vocabulary consistent with the target language, inhibiting words from the language not in use, monitoring speech for intrusions from the other language, and disengaging and engaging in language when switching back and forth (Abutalebi & Green, 2016). These processes all contribute to increasing CR because they are cognitively demanding tasks that are completed regularly, depending on the context of the language use. In terms of differential functionality, a study by Mouthon et al. (2019) demonstrates how the use of a second language increases efficiency of network use in university student translators who were moderately (LP) or highly proficient (HP) in their L2.e participant name the object in the given picture in their first language (L1) and/or L2 depending on the task conditions. The authors found that the HP group exhibited activation in the general control network whereas the LP group exhibited activation in the language control networks. The language control network is larger and responsible for linguistic-related cognitive processes while the general control network is responsible for more general processes such as planning. The findings suggest that with higher L2 proficiency, there is less reliance on the language control network as controlling the two languages can be done with the same resources as any other general cognitive task. This corresponds to what Stern wrote about efficient network use where the more difficult the task, individuals with higher reserve tended to show less activation in task-related areas (less activation in language networks for language-related tasks) compared to those with less reserve recruiting more of the task-related areas (Stern 2002).

The language control network consists of several key brain regions. These include the dACC/pre-SMA complex, left prefrontal cortex, right inferior frontal cortex, inferior parietal lobules, cerebellum, and subcortical structures like the thalamus, left caudate, and left putamen (Abutalebi & Green, 2016).

Some of these structures experience an anatomical change from continued use by bilinguals. One such case mentioned by Abutalebi and Green is the dorsal ACC (dACC) and pre-supplementary motor area (pre-SMA), which are involved with conflict resolution, language selection, and language switching. Studies reviewed by these authors have found increased gray matter density, often measured as the mass of neuronal cell bodies in grams per cubic cm, of the dACC in bilinguals (Abutalebi & Green, 2016). Borsa et al. (2018) conducted a study with older bilingual and monolingual adults that investigated the cognitive and neural hypotheses at the same time. Gray matter volume (GMV) of the ACC, one of the region of interests that were selected, showed to be a strong predictor of interference and conflict effects in the cognitive control test Attentional Network Task (ANT) in older bilingual adults, which was not the case for the monolingual group. Gray matter volume (GMV) of the ACC, one of the region of interests that were selected, showed to be a strong predictor of interference and conflict effects in the cognitive control test Attentional Network Task (ANT) in older bilingual adults, which was not the case for the monolingual group. An interesting finding from this study was that the mean GMV between the monolingual and bilingual groups had no significant difference, which contrasts with previous studies that did find a difference (Abutalebi et al., 2015). One possible explanation could be the proficiency level of the L2. It is hard to tell if proficiency levels in the L2 were close to proficiency in L1 in Borsa et al.'s study as a result. Another difference is the age of acquisition (AoA) of the L2, where in Borsa et al., 2015, the mean AoA was 6.20 years compared to 12.68 years in Abutalebi et al. (2015).

In addition to gray matter, white matter, and the amount of myelinated neuronal axons per unit volume may also be affected by a bilingual experience. In a study by Luk et al., white matter integrity was found to be higher in older bilingual people, and they also displayed stronger white matter connectivity between anterior-posterior regions of the brain. These results have been interpreted as possible explanations for previous research showing older bilinguals to have higher levels of cognitive control than their monolingual counterparts (Luk et al., 2011). Olsen et al. have also found an increase in overall brain volume, including both gray and white matter, in the frontal and temporal lobes compared to monolinguals. These differences are interpreted to enable bilingual individuals to access a larger network of brain regions and stronger connectivity (Olsen et al., 2015).

Bilingualism, as mentioned earlier, is a continuum of L2 proficiency. Higher proficiency level is associated with increasing gray matter volume (Abutalebi & Green, 2016) and the evolution of the mechanisms of language control (gradually shifting resourcing from language-specific networks to general cognitive networks) (Mouthon et al., 2019). To put it another way, the benefits of bilingualism are given in a "dose-dependent manner" (Sala et al., 2021), which emphasizes the bilingual continuum.

Bilingualism may also affect networks involved in executive function. In a literature review comparing the effects of bilingualism on memory systems and executive functioning systems, it seems that the effects of bilingualism act via the protection of executive functioning networks rather than the protection of memory circuits (Gold, 2015), which dementia mainly impacts. Continuous language switching requires a great deal of control, which with overuse, indirectly strengthens general executive control systems through old age (Gold et al., 2013; Gold, 2015). It has been hypothesized in one study that increased activity in frontoparietal and frontostriatal networks that are associated with the bilingual experience can lead to neuroprotection against the decline in the executive control circuits (which involve frontostriatal and frontoparietal networks) (Gold et al., 2013). This is supported by that study's findings comparing older adults' performance in a task-switching paradigm involving switching between colors and shapes. Older bilinguals outperformed older monolinguals with less effort, indicated by requiring less activation, suggesting that switching in language also improved the ability to switch in general areas outside of language (Gold et al., 2013).

The protective effect of bilingualism against the expression of AD symptoms has been evidenced, as well as its protective effects against age-related decline.

Bilingualism and Alzheimer's Disease

Alzheimer's disease (AD) has been consistently listed as one of the top causes of death among older adults. The main etiologic theory of AD is the Amyloid Cascade Hypothesis: the accumulation of amyloid-β peptide in the brain is a significant cause for the development of AD (Karran et al., 2011), of which the main components are amyloid plaques, neuritic plaques, and neurofibrillary tangles (NFTs) (Thal et al., 2013). Dementia is sometimes a symptom resulting from this disease, and progression to this stage can often be predicted with the presence of mild cognitive impairment (MCI). MCI is characterized by cognitive impairment that cannot be considered normal healthy cognition but is also insufficient to be diagnosed with AD (Voits et al., 2020).

With respect to reserve and the expression of AD symptoms including MCI, previous research provides evidence for brain reserve or cognitive reserve to be responsible for the delay in onset of dementia symptoms (Voits et al., 2020). To summarize, patients diagnosed with Alzheimer's who are bilingual can demonstrate similar cognition functioning to their monolingual counterparts with greater brain atrophy, or a decrease in brain tissue. It is also suggested that bilinguals are able to maintain normal cognitive processing by making up for brain atrophy by using alternative networks that do not use the atrophied brain regions. This aligns with the study by Sala et al. (2021), where despite exhibiting similar levels of cognitive impairment, bilinguals with AD showed greater levels of cerebral hypometabolism than monolinguals. Cerebral hypometabolism is when the brain is consuming less glucose than normal, and can be indicative of damage.

It has also been found that bilingual patients rely on alternative network use than normal ones that may have been affected by AD pathology. This is indicative of compensation due to the context of a brain injury, in this case damages caused by AD. A common conclusion in the study of bilingualism as a lifestyle is that it can delay the onset of Alzheimer's disease symptoms by around 4-5 years (Bialystok et al., 2007; Craik et al., 2010). Studies reviewed by Gold also find delays of 3 years for multilinguals, 4.5 years for native-born bilinguals, and 6 years for illiterate bilinguals (Gold, 2015).

While some argue that reserve slows the decline rate, others argue that both monolinguals and bilinguals experience decline at the same rate. However, bilinguals still maintain functioning for several years before they begin to experience cognitive impairment. Bialystok et al. supports the latter theory, with their study–of bilingual and monolingual patients meeting criteria for AD with dementia or other dementia-related neurodegenerative disorders–showing both groups display similar rates of cognitive descent, but bilinguals have better cognition than monolinguals despite that because they have more CR to compensate for degeneration (Bialystok et al., 2007). This is also in agreement with the study by Sala et al. (2021) regarding cerebral hypometabolism described earlier.

The neural explanation of this effect is in its initial stages of study but is suggested to be that bilingualism mitigates atrophy not through memory systems but through executive function systems. Gold's hypothesis states that an increase in activity in the frontoparietal and frontostriatal networks, both of which are part of executive function systems, due to inhibiting and switching caused by bilingualism may protect against decline in executive control circuits. Neural mechanisms that arise from this include increased neuronal activity, enhanced glucose/oxygen delivery, myelination, myelin protection, and others (Gold, 2015). In other words, the usage of two languages may accumulate more reserve via adaptations in neural mechanisms within the executive functioning/control networks.

Bilingualism and Parkinson's Disease

Parkinson's disease (PD) is a disease that affects the nervous system, causing motor symptoms including tremors and/or stiffness (Mayo Clinic, 2023). In addition to motor symptoms, people with PD may also exhibit a range of cognitive impairment: healthy, mild cognitive impairment (PD-MCI), and dementia (PDD). PD has a range of etiology, including both genetic and environmental factors that make it a heterogenous disease (Voits et al., 2020). Pathology is largely characterized by loss of dopaminergic neurons in the nigrostriatal pathway of the brain, which can cause the motor symptoms that are often associated with Parkinson's (Poletti et al., 2011).

Neurologically, Parkinson's affects both gray and white matter structure and integrity. Notable regions of gray matter affected that may explain MCI are the basal ganglia, thalamus, caudate nucleus, putamen, hippocampus, amygdala, and nucleus accumbens. There have been findings that these regions are associated with deterioration in attention, executive functioning, and cognitive decline (Aarsland et al., 2017). There is widespread thinning of cortical gray matter that is associated with increased cognitive decline. Before gray matter deterioration, however, white matter is impaired first and has been found to predict the course of cognitive decline in PD patients towards PD-MCI (Voits et al., 2020).

In terms of the relationship between PD symptoms and CR, one of the most commonly studied proxies seems to be education. Like bilingualism, education can also impact the amount of CR an individual has because it can require more controlled processes and conceptualization abilities (Le Carret et al., 2010). In a systematic review of cognitive reserve and PD, Hindle et al. only found studies that used education as a proxy in their search that included education, occupation, and leisure activity (Hindle et al., 2014). Their review shows that while there was a significant association between higher education level and better performance on cognitive tests, there is insufficient evidence to make the conclusion that cognitive reserve has enough of an impact to delay the onset of PD-related cognitive decline or dementia. Another review that looked at PD-MCI and cognitive reserve also found education to exert a protective effect against cognitive decline (Poletti et al., 2011), and that having more education can decrease the risk of progressing from healthy cognition to PD-MCI (Gu & Xu, 2022). However, further research would be required to investigate the underpinnings of this relationship, along with investigation of how other proxies of cognitive reserve may affect MCI differently. Ciccarelli et al. tries to diverge from using solely education to measure reserve by including other factors like intelligence, occupation, and leisure activities (Ciccarelli et al., 2022). Through this new operationalization, they found that cognitive reserve is also associated with creative and cognitive leisure activities, such as playing music, along with education for both PD patients and healthy controls. This gives potential for bilingualism to have an impact on the progression of cognitive impairment in PD-diagnosed individuals.

In contrast to education and intelligence, bilingualism and its relation to PD is severely under-researched. There are only two studies to date (Hindle et al., 2015; Fishman et al., 2021) that investigate the two, specifically testing whether the cognitive reserve model holds in the face of cognitive impairment (Stern, 2002). Hindle et al. conducted a study that evaluated executive functioning performance in monolingual and bilingual PD patients with tasks that assess mental generativity and speed, working memory, inhibitions, response conflict monitoring, set shifting and switching, and attention. Results showed there was no significant difference between the two groups, suggesting that the cognitive reserve model does not apply. Similar findings were found by Fishman et al. where there were no significant differences found between bilingual and monolingual PD patient performance in executive functioning, memory, and

and visuospatial domain assessing neuropsychological tests. Bilinguals also performed worse than their monolingual counterparts in both language-related tasks (Boston Naming Task, Test of Adult/Adolescent Word Finding: Verb Naming, Boston Diagnostic Aphasia Examination: Semantic Probe, Vocabulary) and attention/working-memory-related tasks (forward and backward Digit Span test). However, a major limitation of this study in particular is the ratio of bilingual to monolingual patients in the sample, with only 15% being bilingual. One plausible explanation for these results may be that the bilinguals have accumulated more severe atrophy than the monolinguals and are performing with similar cognitive ability, which cannot be known without establishing the amount of pathology each group experienced (Voits et al., 2020). Another explanation Voits et al. raises is the age of onset of PD, which is usually during old adulthood. Because of this, it may take much longer for clear differences to rise. In other words, cognitive impairment was too minimal for a difference to be observed.

Bilingualism and Multiple Sclerosis

Multiple sclerosis (MS) is a disease where the immune system attacks myelin in the central nervous system ("Multiple Sclerosis," 2023). It affects both gray and white matter, with common pathology including demyelination, axonal destruction, and loss of oligodendrocytes (Lassmann, 2018). MS differs from other neurodegenerative diseases in that the age of onset is much earlier (early adulthood between 20 to 40 years), and it presents itself differently person-to-person depending on the damage done (Voits et al., 2020; NIH). There are four subtypes of MS: relapsing remitting MS (RRMS), primary progressive MS (PPMS), secondary progressive MS (SPMS), and progressive-relapsing MS (PRMS). The progressive subtypes are continuous, consequently having more severe cognitive outcomes. Because MS presentation consists of a variety of symptom presentations with different etiology, it is considered a heterogeneous disease (Voits et al., 2020). This variability results from the widespread development of lesions that can lead to independent cognitive, neuropsychiatric, and motor symptoms (Chiaravalloti & DeLuca, 2008).

While the trend between MS and reserve has not been thoroughly studied as much as that between AD and reserve, there is some evidence supporting the theory that increased cognitive reserve can delay the onset of cognitive decline that comes with the disease. In an investigation to see how cognitive reserve could affect cognitive functioning in MS patients, it was found that MS patients who had higher cognitive reserve performed as well as the healthy controls in tasks that tested processing speed (Symbol Digit Modalities Test – Oral version), working memory (Paced Auditory Serial Addition Test), and verbal learning and verbal memory (Logical Memory Subtests I and II). Healthy controls also outperformed MS patients with lower cognitive reserve (Sumowski et al., 2009). This supports Stern's cognitive reserve model (Stern, 2002) that having higher amounts of reserve can enable an individual to maintain their cognitive functioning in the face of increasing difficulty (task difficulty or difficulty due to damage) because they have learned to use networks more efficiently or recruit more networks.

There has also been literature by overlapping authors that delve further into cognitive reserve and MS specifically. Sumowski and Leavitt authored a review of literature that investigated the types of contributors to cognitive reserve and how they could reduce or delay cognitive decline (Sumowski & Leavitt, 2013). They described two major categories: larger maximal lifetime brain growth (MLBG), which is heritable, and lifetime intellectual enrichment, which is obtained from environmental factors. Essentially, MS patients with larger MLBG are able to withstand more severe brain atrophy while still being able to maintain cognitive functioning. In terms of intellectual enrichment, MS patients who had more intellectual enrichment (i.e. level of education, vocabulary knowledge) could perform better cognitively and, like those with higher MLBG, withstand greater atrophy while maintaining cognitive functioning. This establishes a trend in bilingualism and a delay in cognitive decline in MS patients. Sumowski and others follow up on the ideas of MLBG and intellectual enrichment by conducting a longitudinal investigation, which is a study design that collects data from the same people over a period of time. Results indicated that increased MLBG and increased lifetime intellectual enrichment have led to a delay in the decline of cognitive functioning by 4.5 years, further supporting the cognitive reserve model (Sumowski et al., 2014).

Bilingualism as a cognitive reserve proxy against MS has not been yet thoroughly studied, but there may be some preliminary conclusions that can be made about this relationship. In a study comprising of patients diagnosed with RRMS, Aveledo et al. examined for differences between the performances of bilingual and monolingual patients on the flanker task, assessing monitoring load and cost (monitoring mechanism) and conflict effect, or the time it takes to resolve a conflict like those presented in the Flanker task (inhibitory control) (Aveledo et al., 2021). A flanker task is a test displaying a series of five arrows from which the participant has to determine if the arrows are congruent or not based on the target arrow (middle arrow), and which direction the target arrow is facing as fast as possible. In this study in particular, the arrows are replaced by five fish, and monitoring load and costs were measured by performance accuracy, and the difference in performance between the high-monitoring (equal number of incongruent and congruent trials) and low-monitoring (greater number of congruent trials) conditions, respectively. The bilingual group did as well or better than healthy controls in monitoring, but performed no differently than monolinguals in inhibitory control. On the other hand, in a study of patients diagnosed with RRMS that compared the executive functioning tasks of bilinguals and monolinguals showed the bilingual group only outperformed the monolingual group with significance in non-verbal tasks involving both attention and inhibitory control (Soltani et al., 2018). As of now, there are not any conclusive theories that can be made about how the bilingual experience could

impact MS symptoms with regards to inhibition and attention. It is especially difficult to identify differences that occur potentially because of bilingualism because the advantages that are seen with bilingualism are more prominent in older populations (Aveledo et al., 2021; Gold et al., 2013). There is also the need to address the heterogeneity of MS presentation which could also be a confounding source to some of these results. Because participants were diagnosed with RRMS, the subtype of MS least subject to cognitive decline, they may not have experienced sufficient impairment to demonstrate a significant difference between monolinguals and bilinguals in executive functioning performance (Aveledo et al., 2021; Voits et al., 2020). While there is still more research that would need to be done, there is potential for bilingualism to have a positive impact on people diagnosed with MS in maintaining some of their executive functioning.

Conclusion

Bilingualism and AD has been much more thoroughly studied than with PD, MS, or other neurodegenerative diseases. However, given the findings of previous research, it is becoming important to investigate these other probable links especially with bilingualism becoming a recurring cognitive reserve proxy in reserve studies.

Bilingualism, specifically for those who have been bilingual since a young age, is classified as having the potential to increase both brain and cognitive reserve because the control of languages in use lead to anatomical structural adaptations and functional activity. In the case of Alzheimer's disease, there have been repeated findings of delay in onset of AD symptoms and diagnosis in bilinguals. While PD and MS have not been studied as much, there is potential to find more direct reserve effects because of bilingualism based on the reserve effects by levels of intelligence and education.

While not a cure for these diseases, being able to ground a relationship between neurodegenerative cognitive impairment could provide methods for improving the quality of life for more years in the older adult population.

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