The Role of Multilingualism in the Brain's Developmental Life Span

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Abstract

Multilingualism provides individuals with the intrinsic ability to learn new languages more efficiently than monolinguals. Bilingual and multilingual individuals have obtained skills during early childhood development that translate to other areas in their lives such as the enhancement of processing information presented in their external environment and a greater attention to detail. Through the use of fMRI, researchers are able to pinpoint specific brain regions that exhibit differences between monolinguals and multilinguals such that multilinguals display a greater tissue density in certain brain regions in comparison to monolinguals. Alongside these visual variations, this article places emphasis on the role of multilingualism throughout an individual's life span as it depicts the neurological benefits such as the maintenance of a cognitive reserve and the protection from age-related decline predominantly seen in dementia and Alzheimer's disease.

Multilingualism is defined as the use of several languages while bilingualism is the use of two languages. Researchers have primarily focused on exploring the differences between bilingualism and multilingualism by analyzing their advantageous roles in the developmental life span of the brain. Multilingualism has the potential to bolster the economy by creating a more diversified and advanced workforce. Research fellow Gabrielle Hogan-Brunab, at the University of Bristol made connections between data that models the relationship between economic growth and linguistic diversity (Hardach, 2018). Switzerland exemplifies this research, as its multilingual heritage makes up 10% of its GDP, indicating that languages have the potential to create new trade relations (Hardach, 2018). Beyond its immediate economic benefits and financial rewards, multilingualism has shown to have remarkable impacts on brain health through improved concentration, and information processing. Moreover, it can impede the onset of dementia (Hardach, 2018). In a similar manner, multilingualism holds a prominent role in early childhood development as it has shown to improve learning and adaptability to external environments (Marian and Shook, 2012). This paper will explore the differences in cognitive functioning between monolingual, bilingual, and multilingual brains, and the benefits of bilingualism in early childhood development as well as in old age.

The two main cortical regions that are associated with language are the Broca's area (BA) and the Wernicke's area (WA) (Mohades et al., 2012). The BA is located within the left inferior frontal gyrus and is known for its function in language output (Dronkers et al., 2007; Mohades et al., 2012). On the other hand, the WA is a left posterior temporal area that is known for its function in language input or language comprehension (Mohades et al., 2012). The connection between the white matter tracts and the gray matter subdivisions of the WA establishes a dorsal link (Mohades et al., 2012). Moreover, the dorsal white matter connections that are located between the temporal and inferior frontal language cortices follow both the arcuate fasciculus (AF) and the superior longitudinal fasciculus (SLF) pathways (Catani and Mesulam, 2008, Catani et al., 2002, Catani et al., 2005, Crosby et al., 1962, Nieuwenhuys et al., 1988; Mohades et al., 2012). According to Angela D. Friederici, Director and Scientific Member of the Max Planck Institute of Cognitive Neuroscience, it is extremely difficult to distinguish between these two pathways given how unreliable and deficient the spatial resolution limitations of the current DTI methods are (Friederici, 2009; Mohades et al., 2012). As a result, the two pathways are regarded as a single dorsal language pathway that can be noted as: AF/SLF (Mohades et al., 2012).

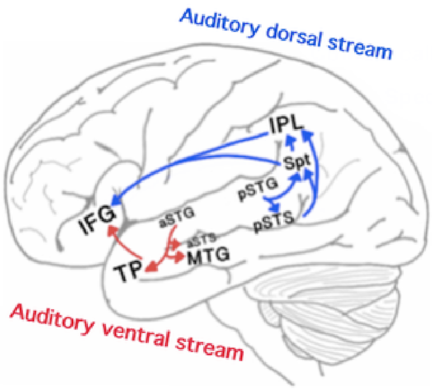

Figure 1. The 2 pathways in the brain that are responsible for language processing are: the auditory ventral stream and the auditory dorsal stream. The auditory ventral is responsible for sound recognition while the auditory dorsal stream is used for sound localization and the articulation of speech (KarinaCor, 2016).

Neurological processing and structure in bilingual and multilingual brains greatly vary from monolingual brains, so it is important to first interpret the general differences between individuals who are monolingual, bilingual, and multilingual. Data from fMRI and MEG studies have presented significant differences in bilingual and monolingual brain functioning during tasks encompassing linguistic and non-linguistic processing (Mohades et al., 2012). Bilingualism studies in general focus on aspects such as language interference and the ability to switch between two languages (Crinion et al., 2006; Marian et al., 2003; Mondt et al., 2009; Rodriguez-Fornells et al., 2002; Mohades et al., 2012). Common examples of nonlinguistic cognitive tasks would include testing speed processing, auditory working memory, and attentional control. In contrast, linguistic cognitive activities would encompass selective attention, grammatical judgment, and social language skills. Ultimately, these studies have found that bilinguals engage with both common and specific cortical areas in order to use their two languages (Crinion et al., 2006; Marian et al., 2003; Mondt et al., 2009; Rodriguez-Fornells et al., 2002; Mohades et al., 2012). Other studies have presented findings regarding the structural plasticity of bilingual brains by analyzing differences in density of gray and white matter in bilingual and monolingual individuals. Results from these studies suggest that bilingual individuals have more gray matter density in the left inferior partial cortex than monolingual individuals but no differences in cortical white matter (Mechelli et al., 2004; Mohades et al., 2012).

Another study reveals that there are noticeable structural differences in white matter tracts between bilingual and monolingual children. The results of this study ultimately determined this by analyzing the fractional anisotropy (FA) and by tracking the left inferior occipitofrontal fasciculus (lIFOF) which connects the anterior regions of the frontal lobe with the posterior regions of the temporal and occipital lobes (Mohades et al., 2012). The FA is a quantity that measures the direction that the water diffuses through, which signifies white matter anisotropy as well as fiber organization (Mohades et al., 2012). The FA value is dependent on the number, density, and size of the axons along with the extent of their myelination (Basser et al., 2000; Schmithorst et al., 2005). The study's goal was to use the FA to compare the white matter microstructure of the four language pathways which encompassed the four bundles of fibers - namely the lIFOF, left AF/SLF, AC-OL, and AMB-PMC. Through tracking the lIFOF, researchers found that the mean FA value of the lIFOF in simultaneous bilinguals was 0.548 ± 0.019, the sequential bilinguals demonstrated a mean FA value of 0.526 ± 0.025, and the monolinguals depicted a mean FA value of 0.516 ± 0.025 (Mohades et al., 2012). These values represent the mean FA for each bundle and their respective standard deviations (Mohades et al., 2012). All of these values present an unequivocal trend of there being a higher mean FA value in simultaneous bilinguals than monolinguals and sequential bilinguals (Mohades et al., 2012).

The results of this study were significant and illustrated a higher anisotropy of white matter over the lIFOF in simultaneous bilinguals which further proved that they are faster in semantic processing and transmission of semantic information than in monolinguals (Mohades et al., 2012). Additionally, language researchers have found a lot of variability in certain tracts within the corpus callosum. These differences indicate that there is variation in bundles between bilinguals and monolinguals in a wide range of linguistic traits such as verbal fluency, reading, writing, and dyslexia (Beaton, 1997, Castro-Caldas et al., 1999, Gazzaniga, 2000, Hines et al., 1992, Hynd et al., 1995, Nosarti et al., 2004a; Mohades et al., 2012).

Bilingual individuals experience many advantages in regards to executive functioning. Executive functions control one's

Researchers have used functional magnetic resonance imaging (fMRI) to identify which brain regions are active when bilingual individuals are performing tasks and switch languages in the midst of those tasks (Marian and Shook, 2012). The studies concluded that the participants have shown an activation in the dorsolateral prefrontal cortex (DLPFC), the anterior cingulate cortex (ACC), bilateral supramarginal gyri, and left inferior frontal gyrus (left-IFG) (Marian and Shook, 2012). These structures are associated with executive function. The left-IFG specifically, is known as the language production center of the brain and has roles in both the non-linguistic and linguistic cognitive control (Marian and Shook, 2012). Similarly, the DLPFC is responsible for attention and inhibition (Marian and Shook, 2012). The left inferior occipitofrontal fasciculus's role is to connect to the inferolateral and dorsolateral frontal cortex in conjunction with the posterior temporal and occipital lobe, which extends below the insula and along the inferolateral edge of the claustrum (Catani et al., 2002, Jellison et al., 2004; Mohades et al., 2012). This large bundle is consequently responsible for language semantic processing (Duffau et al., 2005, Leclercq et al., 2010, Mandonnet et al., 2007, Rodrigo et al., 2008; Mohades et al., 2012).

Researchers have deduced that playing simple speech sounds for monolingual and bilingual adolescents in the presence of background noise sheds light on their sensory processing capabilities. They uncovered that bilingual adolescents were able to express a large neural response which ultimately translated to a higher efficiency in encoding the sound's fundamental frequency and pitch perception (Marian and Shook, 2012). Blood flow in the brain is considered an accurate measure of neuronal activity. The aforementioned study also discovered that bilingual individuals had more blood flow in the brain stem in response to sound, proving that they exhibit a larger neural response. Therefore, bilingual speakers have an enhanced auditory attention which can be owed to their advanced ability to encode sound. In essence, bilingual speakers have more efficient cognitive control mechanisms and sensory processing capabilities (Marian and Shook, 2012). Being bilingual or multilingual can serve an individual with a multitude of benefits that can last them a lifetime. In particular, these benefits and differences are initiated during early childhood development. In bilinguals, the construction of brain circuitry occurs earlier in life and the pathways that promote the learning of the first language are well-developed (Berken et al., 2017).

While it is difficult to pinpoint the specific cognitive processes in bilinguals that give them an advantage over monolinguals, there is research that supports that young bilinguals are able to perform better than monolinguals on tasks requiring high executive functioning. These tasks require participants to select the best response from a set of options, and discard other unimportant information (Kuzyk et al., 2020). These tasks, when administered as early as infancy to 6- and 7-month-olds that have had exposure to bilingual input specifically, show that bilingual children have more efficiency in attention than monolinguals (Kovács & Mehler, 2009; Singh et al., 2015; Kuzyk et al., 2020). This study used the Stroop task which entails individuals to see a word and then being asked to say the color of the font presented on the word (Marian and Shook, 2012). Inhibitory control was explored in the study and is defined as the suppression of behavioral responses and stimuli that is irrelevant to its goal (Tiego et al., 2018). The study ultimately demonstrated that 24-month-old bilingual toddlers performed better than monolinguals on inhibitory control as they disregarded unnecessary more efficiently information which was measured by a modified Stroop task (Carlson & Meltzoff, 2008; Poulin-Dubois, Blaye, Coutya, & Bialystok, 2011; Kuzyk et al., 2020).

Despite these research findings, it is important to be mindful of the fact that these discrepancies illustrate that there are variances in the language pairs that the bilinguals speak, the age of acquisition of their languages, and the proficiency of their spoken languages (Kuzyk et al., 2020). With that in mind, some researchers have proposed that individuals with a more balanced proficiency in their spoken languages are more likely to have an advantage in inhibitory control (Prior, Goldwasser, Ravet-Hirsh, & Schwartz, 2016; Kuzyk et al., 2020). Executive function can be divided into three connected abilities: cognitive flexibility (which involves the ability to shift between mental sets), examining working memory representations, and impeding responses or distracting stimuli (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Kuzyk et al., 2020). Abundant evidence suggests that bilinguals have cognitive advantages during conflicting tasks and older bilingual adults are efficient in managing conflicting attentional demands through interference suppression (Bialystok, Craik, Klein, & Viswanathan, 2004; Kuzyk et al., 2020). However, there is also evidence of cognitive benefits seen in children performing conflict tasks (Poulin-Dubois et al., 2011; Kuzyk et al., 2020). In essence, bilinguals demonstrate a higher efficiency in suppressing inferences than monolinguals (Kuzyk et al., 2020)

Individuals who are multilingual or bilingual exhibit various learning improvements specifically pertaining to cognitive and sensory processing (Marian and Shook, 2012). These enhancements allow for bilinguals to have a keen ability to process information in their external environment leading to an enhanced ability to learn new things. This also explains why bilingual adults are able to learn a third language better than monolingual adults striving to learn a second language (Marian and Shook, 2012). Another plausible explanation is that bilinguals may have an advantage in learning that stems from their ability to solely focus on the information presented in the new language while simultaneously minimizing the interference of information from their previously learned languages (Marian and Shook, 2012). Bilinguals consequently have a better vocabulary due to their capabilities of comfortably recalling and accessing newly learned words (Marian and Shook, 2012). Peal and Lambert conducted studies on children in Montreal who were either French-speaking monolinguals or English-French bilinguals and measured their performances on a battery of tests (Marian and Shook, 2012). Peal and Lambert predicted lower scores in the bilingual group but instead observed that the bilingual children scored the highest on most of these tests, particularly on tests that involved symbol manipulation and reorganization (Bialystok et al., 2012). These conspicuous differences between monolingual and bilingual children led to further analysis of this phenomenon in studies. These studies demonstrated the remarkable advantages that bilingual children had in their abilities to solve linguistic problems through the use of metalinguistic awareness and nonverbal problems (Bialystok et al., 2012). In essence, many researchers have shown that the advantages of knowing multiple languages go beyond the linguistic benefits that can last a lifetime.

The neurological benefits seen in multilingual and bilingual infants, children, and young adults, continue to extend past early childhood development and into old age. One study focused on lifelong bilinguals in their old age, the maintenance of their cognitive functioning, as well as the delay of the onset of dementia symptoms (Khan, 2011). Within this study, there were 228 patients and 51% of them were bilingual and had a wide array of differences concerning cognitive impairment that were closely monitored in a memory clinic (Khan, 2011). The study concluded that the monolinguals presented symptoms of dementia about 4 years earlier than the bilinguals. The other components of cognitive tests remained the same (Khan, 2011). Another study by Howard (2010) was conducted in Montreal, Canada. This study examined multilingual immigrants who were suffering from Alzheimer's dementia as well as bilingual non-immigrants who grew up speaking French and English in Canada (Khan, 2011). The study consequently reported that participants who could speak two or more languages had a delay in the onset of dementia for an average of 5 years (Khan, 2011). Overall, these findings illustrate the point that bilinguals and multilinguals have a substantial delay of the onset of dementia of about 4-5 years and further proves how multilingualism has the ability to protect against age-related decline.

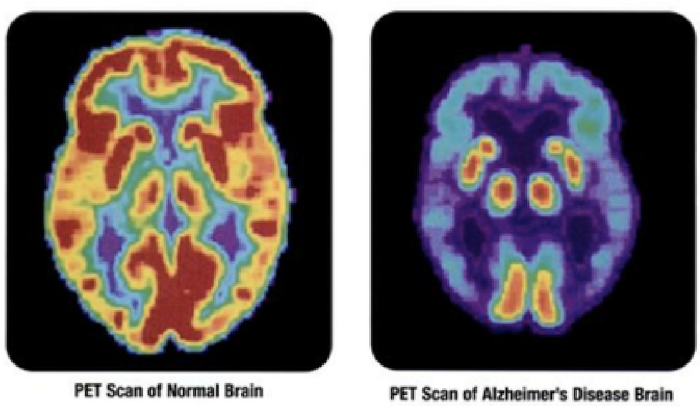

Figure 2. These PET scans depict the differences in brain composition and size between a healthy individual as shown on the left and an individual with Alzheimer's Disease, as shown on the right (Health and Human Services Department, National Institutes of Health, National Institute on Aging, 2013).

Another cognitive benefit of bilingualism is its ability to avert the diminishing of cognitive function and maintain a “cognitive reserve” (Marian and Shook, 2012). A cognitive reserve encapsulates the effective use of brain networks, which augments brain function during the aging process (Marian and Shook, 2012). Bilingualism can contribute to the reserve through the maintenance of cognitive mechanisms as well as the involvement of alternate brain networks. These processes indemnify those circuits that are damaged with age (Marian and Shook, 2012). Older bilingual individuals also exhibited improved memory and executive control in comparison to monolingual individuals (Marian and Shook, 2012). Alongside cognitive benefits, studies that consisted of older and younger individuals, investigated neuroplastic changes in bilinguals and monolinguals. The researchers consequently discovered language group differences in grey matter regions of the brain which are associated with executive function and the control of language (Duncan et al., 2018). Amongst these differences, the older bilinguals exhibited a higher amount of brain matter in comparison to the monolinguals specifically in the left anterior inferior temporal gyrus (Abutalebi et al., 2014) as well as the left and right inferior parietal lobe (Abutalebi et al., 2015a), and both hemispheres of the anterior cingulate cortex (Abutalebi et al., 2015b; Duncan et al., 2018). While on the other hand, the younger adults depicted increased amounts of brain matter in the left inferior frontal gyrus (Klein et al., 2014), the left Heschl’s gyrus (Ressel et al., 2012), the left putamen (Abutalebi et al., 2013), the right and left supramarginal gyri (Grogan et al., 2012), and the left and right cerebellum (Pliatsikas et al., 2014; Duncan et al., 2018). In effect, these findings suggest that bilingualism is linked to greater tissue density and thicker cortex than presented in the monolinguals of the study (Duncan et al., 2018).

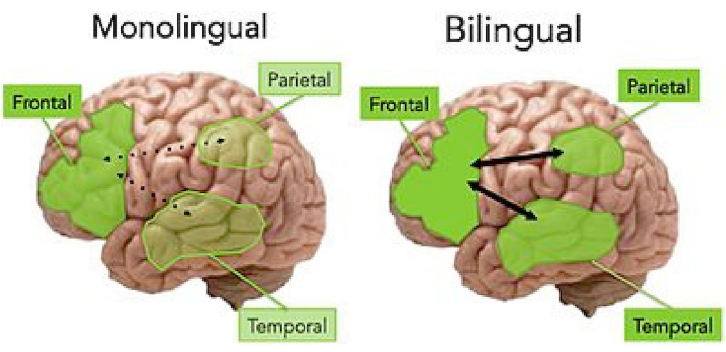

Figure 3. This image encapsulates the differences between the monolingual and bilingual aging brain as the bilingual aging brain presents more connectivity between frontal and posterior areas which form a cognitive reserve. The monolingual aging brain demonstrates a link to a heavier reliance on the frontal regions.

Multilingual and bilingual individuals possess a multitude of benefits such as an enhanced and sharpened cognitive ability which persist throughout their lifespan. Visual representations in fMRI scans demonstrate these specific differences in brain regions between monolinguals and multilinguals. The advantages of being multilingual during early childhood development include improvements in executive function, auditory attention, and the coordination of cognitive tasks in daily life. In older adults, studies have demonstrated the neurological benefits of being multilingual and bilingual and its potential to setback onset symptoms of dementia and Alzeheimer’s Disease. Given these exceptional impacts seen throughout an individual’s life span, one should strongly consider teaching themselves or their children a second or third language as the benefits can reap rewarding impacts on one’s well-being and pave the path for an innate ability to pick an additional language.

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