The Impact of Bilingualism on the Severity of Aphasia

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Abstract
Aphasia is a common disorder associated with stroke that affects how an individual communicates or processes language. There is ongoing speculation within the neuroscientific community over whether bilingual patients would have an advantage in recovering from aphasia, a language disorder, compared to monolingual individuals. This discussion centers on the potential for bilingualism to confer cognitive and neural benefits that might facilitate language reacquisition after a brain injury or stroke. To demonstrate this, various studies show that bilingualism results in higher cognitive control, which then leads to a faster recovery rate of aphasia. This paper will discuss the effects of bilingualism on post-stroke aphasia, concluding that recovery is aided for both languages when they are linguistically similar. Additionally, this paper will discuss the effects of other factors such as the age of language acquisition, the age of aphasia acquisition, gender, and family language proficiency that must be considered when studying the effects of bilingualism on aphasia (and have been severely understudied). Results for this proceed to conclude that while gender does not significantly impact recovery, early late age of acquisition for L2 and family proficiency have an inverse correlation with the severity of the symptoms and a direct correlation with the recovery rate of aphasia. By studying the role of bilingualism on the severity of aphasia, this research can provide valuable insights into aiding the recovery of post-stroke aphasia and possibly help open future forms of intervention or treatment.

Part 1: Aphasia

Brain Regions involved in language

Traditionally, there are two brain regions that have been linked to language processing. These are Werknicke's and Broca's areas, located in the superior temporal gyrus and the frontal lobe, respectively. In 96% of people, language has been localized to the left hemisphere (Wright, 2020). Wernicke's area is critical for speech production by activating a process called phonological retrieval where knowledge about vowels and consonant sounds is activated prior to articulation (Binder, 2015); put simply, Wernicke's area is often linked to the *planning* (and potentially production) of language. In turn, Broca's area works hand in hand with Wernicke's area in order to control the movement of the mouth as well as sentence grammar and flow, primarily shaping comprehension (Reddy et al., 2023).

These regions were first identified in case studies in which individuals that had lesions in Broca's and Wernicke's had respective issues with language comprehension and production. Further, functional magnetic resonance imaging (fMRI) studies have gone on to indicate that language tends to be localized to the left hemisphere in the majority of the population and activates broader regions of the cortex beyond these two traditional regions. In fact, more recent work focuses on the existence of a language network, or a series of regions that operate together in order to support language function. Commensurate findings using DTI (detects how water diffuses across white matter tracts) and tractography (represents nerve tracts using data from diffusion MRI) have provided further support that these regions are functionally and anatomically connected. Furthermore, recent work has demonstrated that this network is universal and preserved across speakers of all language families (See Fig. 1; Malik-Moraleda et al., 2022)(see Fig. 1 for more detail). This implies that there are shared structures that support language and are therefore universally disrupted in cases of aphasia, meaning that damage to the same areas will have consistent effects across patients (for example; a Japanese speaker and an English speaker will have similar issues in their respective languages when having damage to Broca's area). Below, we will discuss how subregions of this network differ in their responses within bilinguals (as compared to monolinguals) and across languages.

Fig. 1. This demonstrates that the language network is conserved across languages and language families. The highlighted regions within each language family represent neuroanatomical similarity and connection. Figure and findings from Malik-Moraleda et al., 2022.

Definition of aphasia, types, & how it is measured

Aphasias, or brain disorders that impact a person's ability to express and understand written or spoken language, typically occur after a stroke or head injury impacts one of these brain regions. Depending on the part of the brain that is affected, there are different types of Aphasia. The most common types include Broca's Aphasia which causes difficulty to speak at a normal rate and Wernicke's Aphasia which affects the ability to comprehend words, resulting in meaningless speech (sometimes called "word salad"). While both can be caused by direct injury or stroke to the Broca's and Wernicke's areas, damage to areas outside these established zones and within the left dominant hemisphere can also result in these two types of Aphasia. For instance, lesions to the dorsolateral prefrontal cortex and the superior frontal gyrus can also lead to Broca's aphasia and are characterized by linguistic deficits similar to lesions to Broca's area itself (Binder et al., 1997). In addition, Transcortical Motor Aphasia, caused by lesions just superior and anterior of Broca's area in the Supplementary Motor Area (SMA), can cause slow or halting speech, yielding similar behavioral effects to Broca's Aphasia despite not targetting that direct region (Freedman, Alexander & Naeser, 1984; Kemenoff et al., 2002) (Refer to Fig. 2 for more descriptions on the different types of aphasia). Other types of aphasia include conduction aphasia which causes the speaker's inability to repeat words or phrases. The area affected includes the arcuate fasciculus, impairing the transmission of information between the Wernicke area and the Broca area (Acharya & Maani, 2023). This further emphasizes the degree of connections between regions in driving these behavioral effects.

Speech-language pathologists often test individuals with a Comprehensive Aphasia Evaluation. In this exam, factors such as case history, interviews with the patient and family, informal conversation, and language sample along with the inclusion of an Oral Motor Exam are utilized to determine the severity of the onset of aphasia (Sebastian & Sheppard, 2022).

Given the diversity of aphasias, it is often difficult to pinpoint the exact outcome and whether language function can be regained. However, recent work has established that access to multiple languages before the onset of neural damage can alleviate the degree of aphasia. In this paper, we aim to discuss how access to different languages, specifically two languages ("bilingualism"), can impact post-stroke aphasia outcomes including symptoms and severity. We also introduce additional factors that may mediate these outcomes.

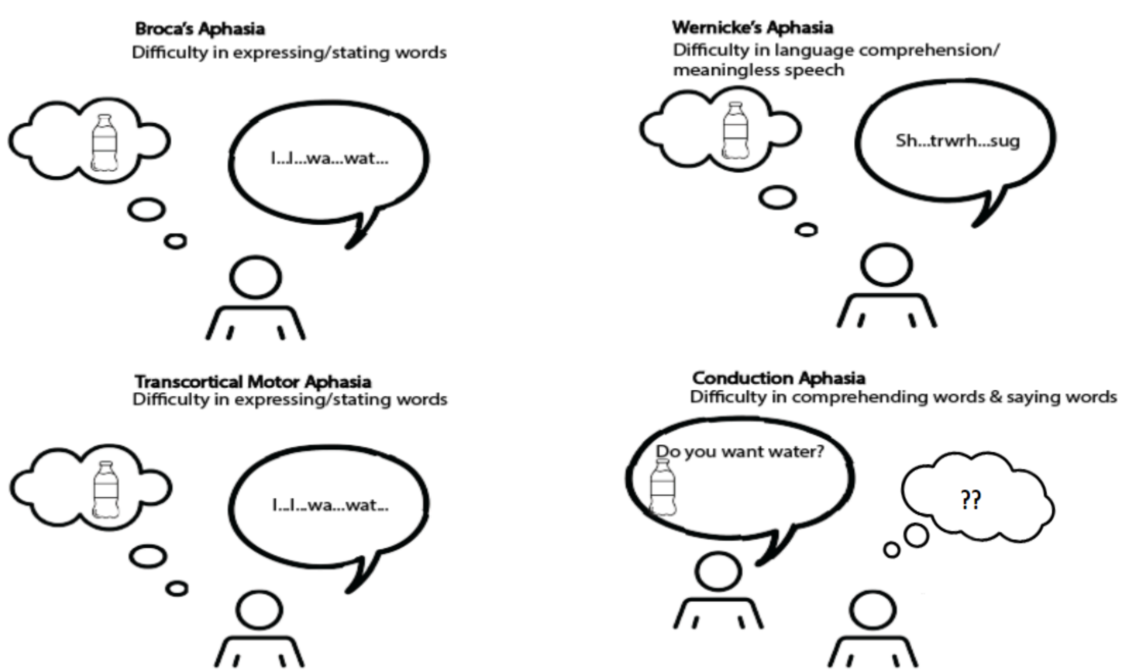

Fig. 2. This shows how different types of aphasia (Broca's, Wernicke's, Transcortical, and Conduction) affect the speech and comprehension of affected individuals.

Part 2: Bilingualism
There has been a tremendous interest in how languages are organized in bilingual individuals, i.e., people who know two languages (Fabbro, 2013). For a long time, there were scientific discussions about whether the addition of a second language early on could lead to developmental delays. However, newer evidence speaks to the contrary as will be discussed here (see Kroll, Bobb, and Hoshino, 2014 for a comprehensive discussion) and, in fact, early-onset bilingualism may have benefits. In this section, I will discuss how the representation of multiple languages is represented in the brain and the benefits of learning a second language early on in life.

Bilingualism in brain regions
Based on neuroimaging studies with healthy volunteers, lesion studies with patients suffering from post-stroke aphasia, and neurosurgical reports using invasive mapping techniques, we know that in the case of bilinguals, their two languages can be represented separately or within shared neuroanatomy (Fernández-Coello et al., 2017; Hernandez et al., 2000; Klein et al., 2002; Paradis, 1977; Perani et al., 1998; Sulpizio et al., 2020). In cases where the two languages overlap in their neuroanatomy, past work has found that there are areas that are co-localized to first (L1) and second (L2) language functions. On the other hand, there have been cases where the first and second languages' representation is spatially different with a decent amount of studies indicating that there is a degree of language-specific processing (Chee, Soon & Lee (2003); Meykadeh et al.,(2021)). Specifically, studies using electrocorticographic stimulation have identified the degree of convergence versus divergence in the representation of L1 and L2 by stimulating a single site and seeing whether this stimulation disrupted one language, both, or neither (Polczynska & Bookheimer, 2021).
The degree of neuroanatomical overlap between languages seems to depend on the age of acquisition and the differences between the languages acquired. For instance, prior work has shown that the degree of anatomical overlap decreases when the second language is acquired later on in life (Fernandez-Coello et al., 2017). Similarly, if the languages are similar in syntax or, if they are of more similar language families, their neuroanatomical representation is more similar. For instance, a study conducted by Bolger et al. (2005) demonstrated how there is significantly more brain activity in the right fusiform gyrus and inferior occipital lobe while reading a logographic language such as Chinese as compared to English which is alphabetical, proving how two structurally different languages engage differential brain regions (Chee, Soon & Lee; 2003). In contrast, another study conducted on native Korean trilinguals by Jeong et al. (2007) revealed that Japanese and Korean, two structurally close languages, had more similar fMRI activity than English and Korean which are linguistically more distant (Połczyńska & Bookheimer, 2021). In Part III, I will discuss how these features are also relevant to the degree to which bilingualism aids in the recovery of language post-stroke.

Gray Matter and Bilingualism
A proposed difference between monolinguals and bilinguals is a difference in the amount of grey matter; namely, it has been previously proposed that there is more grey matter in language regions (Mechelli et al., 2004) and executive control regions (EC; Olulade et al., 2016)

in bilingual brains than in monolingual brains (Refer to Fig. 4). A common explanation for these differences is that bilinguals need improved executive functioning due to the need to manage two languages. For instance, Schug et al., (2022) found differences between English monolingual children (ages 8-11 years) and Spanish-English bilingual children (ages 7-12 years) in terms of their grey matter within regions close to EC regions (left precentral gyrus and right superior parietal lobule), but, crucially and interestingly, these regional differences are comparable to what is usually seen in bilingual adults, indicating that the "bilingual advantage" is seen early on and does not need many years of experience with both languages. Additionally, it is noted that languages that involve different levels of cognitive control due to different writing systems (e.g., English and Chinese) may lead to increased cognitive reserve (the brain's resistance to damage) through different mechanisms, thus increasing gray matter density (Antoniou & Wright, 2017). Likewise, prior work has suggested that bilinguals are advantaged in their executive control and cognitive functioning, as indicated by differential activity in non-language, cognitive control, regions such as the anterior cingulate (Abutalebi et al., 2011).

Although there is significant heterogeneity in results when it comes to comparing grey matter (Danylkiv & Krafnick, 2000), it is also worth emphasizing that these gray matter differences may help with attenuating neural atrophy down the line; differences have been shown between monolinguals and bilinguals when it comes to Alzheimer's disease (Duncan et al., 2018) and the implications for aphasia will be discussed in section 3.

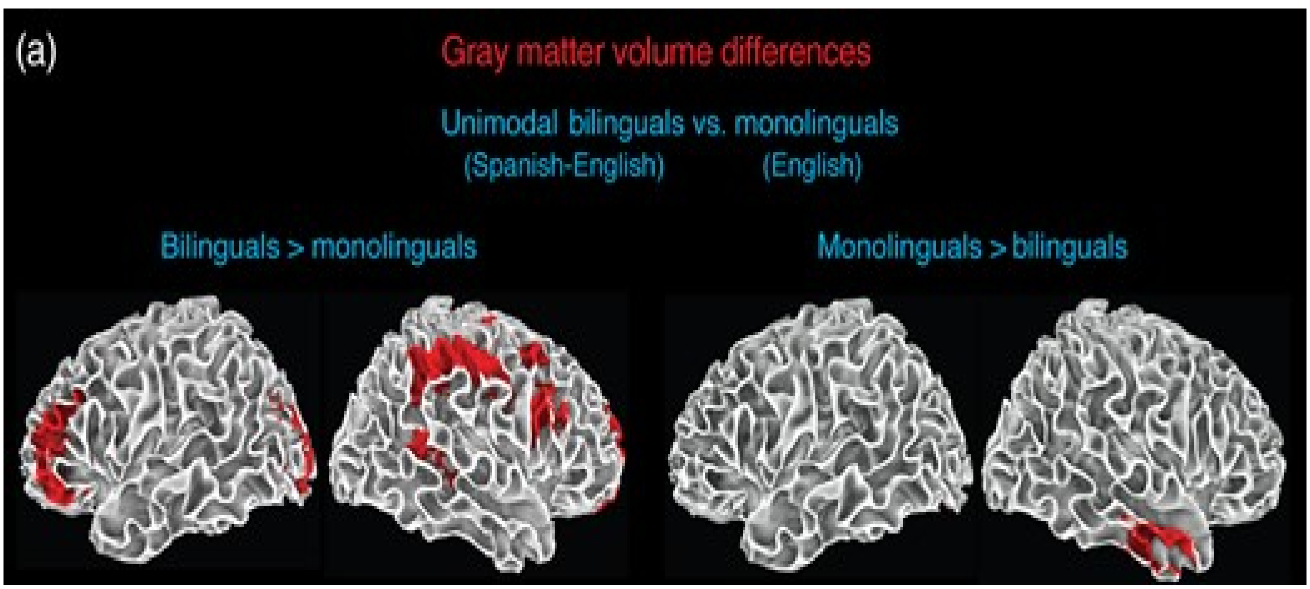

Fig. 4. This demonstrates that there is more gray matter volume in bilingual brains in the linguistic regions as compared to monolingual brains. The red areas represent the greatest gray matter volumes, exhibiting activity in language and control (including memory and emotion) regions. Figure and findings are from Oludelade et al., 2015.

Bilingualism's Impact on Efficiency

Although there is more work to be done, it has been suggested that bilingualism improves the efficacy of neural processing. Bilingual individuals showed higher increases in activation in classic language areas, including the left inferior frontal cortex (LIFC), as compared to monolingual individuals. For instance, by comparing English-speaking monolinguals and

English-Spanish speaking bilinguals, Kovelman *et al.,* (2009) showed that bilinguals had a significantly greater recruitment of the LIFC than monolinguals, as indicated by increases in the blood oxygenation level-dependent signals (BOLD) (refer to Fig. 3). Similar findings were presented in a study comparing language development between bilingual and monolingual babies. Costa & Gallés (2014) found that although first language processing seems to be fundamentally the same for both monolinguals and bilinguals, the L2 for bilinguals required higher processing demands that, in turn, led to an increase in brain activity. Studies have also suggested that the coactivation or parallel activation of both languages in the brain contributes to higher efficiency for bilinguals, demonstrating that bilinguals recognize cognates (words that are similar in structure but could either have the same or different meaning) at a quicker pace than do monolinguals (Kroll et al., 2014). Given all of these findings, it can be concluded that bilingualism positively impacts the cognitive abilities of an individual since different parts of the brain for both languages are being engaged simultaneously.

Based on these neural differences, it is safe to assume that bilinguals may experience language loss differently *and* that perhaps neural differences between bilinguals and monolinguals may give bilinguals an advantage in post-stroke aphasia.

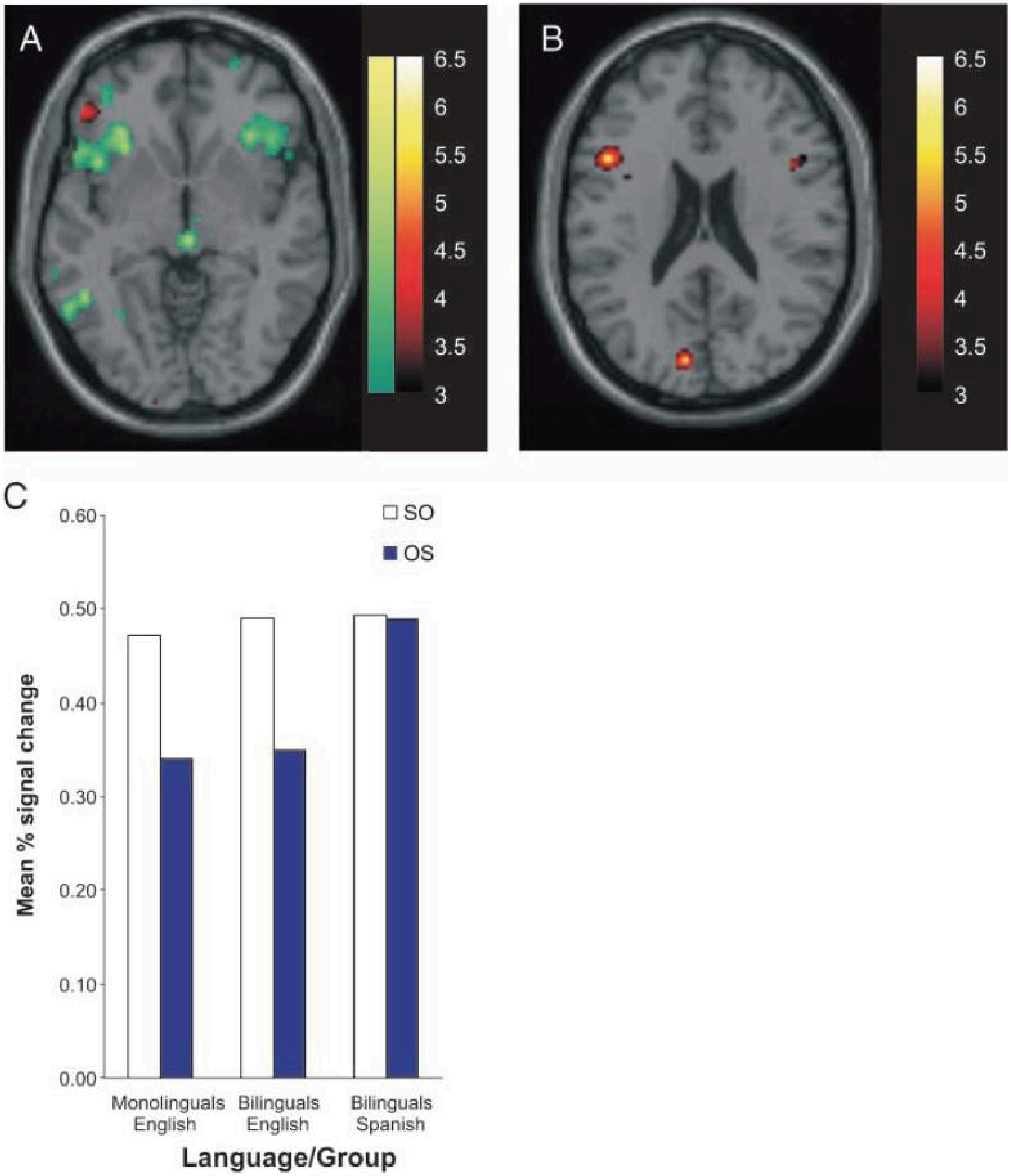

Fig. 3. The brain MRI scanning and the graph demonstrate that bilinguals exhibited greater activity in the left inferior frontal cortex (LIFC) and greater BOLD intensity. Figure and findings from Kovelman et al., 2009.

Part 3: Bilingualism Effect on Aphasia and Other Factors

Bilingualism Effects on Aphasia Recovery

When it comes to addressing how bilingualism affects the severity of aphasia, prior work has suggested that having access to multiple languages aids in the recovery of post-stroke aphasia– i.e., bilingual individuals tend to have a faster and better recovery.

Lahiri *et al.,* (2020) compared Bengali-English bilinguals and Bengali monolinguals as a part of the Kolkata Aphasia Study and identified that bilinguals of both genders, but especially males, had a higher probability of recovering from aphasia as compared to monolinguals. Similarly, other work identified that in contrast to monolinguals, bilingual aphasic patients tend to have a higher probability of improving their processing speed during rehabilitation(De Letter et al., 2020). Therefore, while bilinguals and monolinguals are equally at risk for developing aphasia post-stroke, the aphasia may be less severe in bilinguals (Papliakar *et al.,* 2018).

These results can be further explained by a study conducted by De Letter et al. (2020) where aphasic patients were tested to see if those who are bilingual and have a high enough L2 proficiency can have a higher accuracy for cognitive functions and a faster recovery rate for linguistic abilities such as interpretation, verbal and nonverbal communication, and comprehensible speech (Marinelli et al., 2017).

Importantly, Paradis et al., (2004) discuss four potential recovery patterns for bilinguals with aphasia. Pattern 1 is a parallel recovery where the aphasic patient's recovery is consistent across the two languages. Pattern 2 is differential recovery where one language is recovered better than the other one. Pattern 3 is antagonistic recoery where one language can be used initially and then when the second language becomes available, use of the first starts to regress. Pattern 4 is a blended recovery of both languages where the aphasic patient mixes the two languages (unwillingly) and is unable to speak one language at a time. Interestingly, this can be interpreted as a manifestation of cognitive reserve (Hillis and Tippett, 2014; Watila and Balarabe, 2015). The sections below aim to provide some additional insight into why these patterns may occur.

Linguistic Similarity

Franco Fabbro (2001) addressed the need for more comprehensive tests where bilingual aphasics are tested in both languages to better understand how it aids recovery. According to Kuzmina et al. (2019), linguistic similarity needs to be considered when testing for differential impairments across the two languages in bilingual aphasics, since, as mentioned above, depending on the similarity between languages, the neural underpinnings supporting each language may differ. A study conducted by Roberts and Deslauriers (1999) showed that a group of 15 balanced French-English bilinguals with aphasia were more accurate at naming pictures representing cognates (words that are similar across languages) of the two languages compared to noncognates (Kuzmina et al., 2019).

Similarly, Weekes (2010) presented a study that compared English-French (two similar languages) bilinguals and English-Hebrew (two different languages) bilinguals. The results showed that via treatment in the English language, there was an improvement in the production of language, specifically pronoun-gender agreement, and this effect generalized to the non-treated language when it was more linguistically similar (French), but not when it was more linguistically different (Hebrew) (Weekes, 2010).

Ruch (2020) proposed a similar hypothesis stating that the type of languages bilinguals speak may influence the recovery patterns of Aphasia. For instance, a case study conducted by Hammarstrom (2016) addresses that English and Dutch are both languages that belong to the Indo-European language family, therefore allowing similar and quicker recovery for both languages. The author compares basic vocabulary from both languages to help determine the language family. However, this is not the case with structurally different languages. For instance, it is suggested in an analysis by Weekes (2010) that native Greek speakers whose second language is English (two languages from different language families) produced more verbs and nouns, complicating the recovery process for each language. This provides strong evidence that linguistic similarity is considered to play an important role in whether bilingualism aids in aphasia recovery.

Other Factors (Age, Gender, Family Environment)

The age of acquisition for the two languages also plays an important role in the extent of recovery for each language in aphasics. Kuzmina et al. (2019) showed that there were significant differences between early (L2 acquired before age 7) and late (L2 acquired after age 7) bilinguals. Specifically, late bilinguals showed significantly better overall performance in L1 than in the later-learned language and when L2 was acquired earlier on, it aided more in recovery during aphasia. However, crucially, this would often coincide with language proficiency and frequency of use of each language; people who gained L2s earlier on in life also tended to be more proficient in these languages and therefore, they tended to be more beneficial for recovery. This implies that there may be different underlying representations and processing for earlier as opposed to later acquired languages, but this research is ongoing (Linck et al., 2009; Fabbro, 2001; Kiran & Roberts, 2010; Kuzmina et al, 2019). Of course, while the age of language learning plays an important role in the recovery of language, so does the age of aphasia onset. Older adults have a more difficult time and age seems to be a limiting factor in aphasia recovery altogether (Johnson *et al.,* 2019). Furthermore, older age also tends to co-occur with other diseases which may make language recovery more difficult due to decreases in overall cognition and speed of processing (Brands *et al.,* 2015).

In addition to age, it is also important to consider sex as a possible factor that affects the recovery of post-stroke aphasia. Prior work indicated that females and males process languages differently in the brain, suggesting the need to analyze the impact of gender/sex on the improvement of linguistic control during the recovery of aphasia. For instance, Kaiser et al. (2009) suggests that women tend to have better spelling, language, and grammatical abilities as compared to men, exhibiting greater verbal memory. Although their fMRI study revealed that females showed more function by being active on both sides of the brain while men were significantly more active on the left hemisphere (typically controls speech) of the brain than the right, generally prior work has demonstrated that sex does not play a role in the recovery rate of post-stroke aphasia. According to a study and analysis conducted by Basso, Capitani & Moraschini (1982), it was found that there was no significant statistical difference when the severity of aphasia and the sex of the patient were compared to the recovery rate. Similar findings were demonstrated by more recent papers. For instance, a study conducted by Hachioui et al. (2013) assessed the recovery of 125 patients where 34% recovered within 3 months and 115 patients where 42% recovered within a year. The results were eventually shown to be independent of sex, suggesting that there is no direct correlation between the recovery of aphasia and the sex of the patient (Hachioui et al., 2013).

However, family proficiency in the languages significantly contributes to the proficiency in a language and therefore its ability to aid in post-stroke aphasia recovery (Ardila & Lahiri, 2020). For instance, a study conducted by Kiran *et al.* (2013), testing the confidence levels for English−Spanish bilinguals based on multiple factors (age of acquisition, life exposure, skill before and after the onset of aphasia, and family proficiency), revealed that higher family proficiency in either language contributes to higher confidence levels in either Spanish or English post-stroke aphasia, demonstrating a direct correlation (Kiran et al., 2013). Family proficiency in a language significantly contributes to the patient's own levels of proficiency versus learning the language at school. This is because of higher practice levels in a common setting and more emotional development or connection to the languages spoken.

Conclusion

As bilingualism becomes more popular with approximately 3.3 billion bilingual people worldwide and 67.3 million bilingual people in the US, it is important to understand the effects it may have on the severity of aphasia and whether it can play a vital role in the recovery of post-stroke aphasia. Each year, approximately 100,000–180,000 people in the United States are diagnosed with aphasia, making it a widespread disorder. To help address this issue, this paper aims to serve as a literature review demonstrating that bilingual aphasics tend to have a faster recovery rate for retaining cognitive abilities and language comprehension compared to monolingual aphasics and to provide insight into which factors impact these processes. We hope that future empirical work will investigate the impact of these factors further to aid in the discovery of treatments and recovery practices for aphasia.

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