The Functional Architecture of Language

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Abstract:
Historically, language has always been localized to the left hemisphere of the brain, with studies focusing on linguistic abilities from areas such as Broca's and Wernicke's. Many previous papers describe in detail how these areas function and the possible deficits that occur as a result of damage to these areas, but do little to examine linguistic abilities in other regions. While there are case studies of patients with unusual types of aphasia or having a condition that changes how a linguistic disorder impacts them, they are limited and do little to form their own conclusions. This paper's broader goal is to understand the neurological foundations of language and how the brain supports the neural substrates of language. Specifically, it will discuss how different regions (and networks of regions) support distinct functions that allow for language. It will discuss how functions such as speech production and language understanding are tied to specific regions of the brain beyond the traditional areas cited earlier, and how they are essential to these processes. It will then discuss how brain damage from stroke can alter one or more of these functions, allowing for better understanding of individual functions. It will also cite bilingualism research to demonstrate how multifunctional and versatile the language network is. Altogether, this paper's goal is to demonstrate the complexity of the language network and refute traditional lateralization theories to articulate how the language network has regions in nearly all parts of the brain, proposing that doctors use this information to improve their diagnosis and patient treatment.

Introduction:
The study of language and the brain provides valuable insight into both development and cognition. Language especially allows us to communicate and interact with the world and one another. More than just a critical part of our lives, language represents a key milestone in human development. If a child does not acquire their first language between the ages of 2 and puberty, there is a low chance that they will ever fully grasp it (Fromkin *et al*., 1974). Moreover, if brain areas associated with language are not stimulated early enough, individuals will have difficulty expressing their thoughts (Fromkin *et al*., 1974).

This paper's aim is to show the capacity of the language network through identifying regions that help it function in order to demonstrate why it requires both hemispheres to properly function. This paper will begin by examining the distinct neural regions that support different aspects of language function in order to review what is already widely known about the language network. Next, it will consider how language is best understood as a distributed network made up of both specialized and non-specialized regions working together to support linguistic function to demonstrate that the language network entails many functions. It will then discuss how damage to some of these regions results in aphasias or linguistic deficits to demonstrate the functions that are lost when the area they are tied to is damaged. Finally, it will highlight new research on bilingualism in relation to the brain to show how bilingualism impacts the network and allows it to diversify the functions/regions previously discussed and demonstrate changes towards diagnoses of linguistic conditions. The goal is to review current understandings of language representation, flexibility and plasticity and challenge the idea that language is compromised to the left frontal and temporal lobes. Altogether, this paper reviews recent advances in understanding the neural architecture of language, illustrating how findings regarding classical regions such as Broca's and Wernicke's, distributed networks, linguistic deficits, and bilingualism contribute to a more comprehensive picture that encompasses the many responsibilities of the language network.

Section 1: Distinct neural correlates that support language function

When it comes to the neuroscience of language, a few quintessential regions are foundational to our understanding. Classical theories of language localization (assigned regions for linguistic function) emphasized Broca's and Wernicke's areas as left-lateralized "language centers," resulting in many accepting this simplified theory. Broca's Area (located in the triangular part of the inferior frontal gyrus) was discovered in 1861 when physician Paul Broca studied the brain of an individual named "Tan" who was only capable of saying the word "tan," but was still able to understand language and responded using gestures *(*The Behaving Brain, 2025*)*. Wernicke's Area (located in the mid-anterior superior temporal gyrus) became associated with language in 1874 when neurophysician Carl Wernicke studied the brains of deceased people with the condition now known as Wernicke's aphasia *(*Javed *et al*., 2023; see Section 3 for more details*).* These studies demonstrated the dissociation between language production (i.e., creating and conveying language) and comprehension (i.e., understanding language), with Broca's Area being more specific for production and Wernicke's Area being more specific for comprehension. See section three for more details on Broca's and Wernicke's Aphasias. This early dissociation laid the groundwork for identifying that language functions could be localized. While these discoveries were essential to broadening our understanding of the relationship of language to the brain, this classification system could not explain the full extent of language function.

Section 2: Language as a network

Language Localizers:

Contemporary approaches have expanded on this framework by employing specialized tasks–known as language localizers– that allowed researchers to identify language-selective regions.

Language localizers are a type of experimental task that allows researchers to identify brain regions that are selectively involved in parts of the language processing system. They help to isolate specific language functions to parts of the brain and dissociate them from other related cognitive functions (e.g., abstract thought, mathematics, face processing, etc.). Specifically, language localizers work by contrasting brain activity in a language task (like reading a sentence) to a control task (like reading non-words) Figure 1 below shows an example of a control localizer and the language localizer and contrasts them. This contrast helps identify specific areas involved in high-level processing (understanding & responding) versus those involved in low-level processing (recognition of letters). The goal of language localization is to identify regions that respond *more* to language-related processes than non-language, matched controls (bottom row, Figure 1).

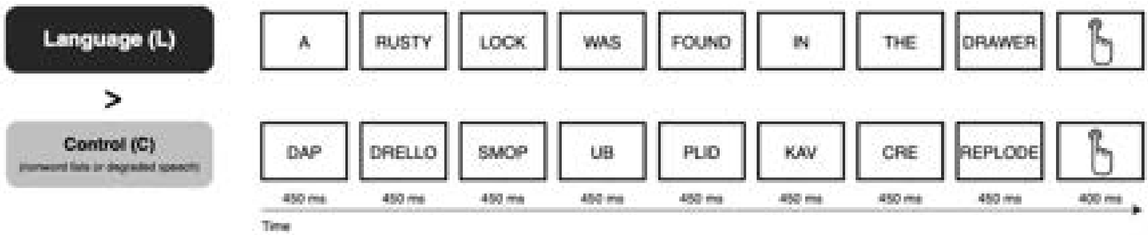

Figure 1: Example of a language localizer. The figure details the two groups of words and non-words used in localizers. The top row illustrates words expected to induce brain activity in response to language, which would be contrasted to the decreased response to non-words in the bottom row (Adapted from Casto *et al.,* 2025).

Notably, studies have been conducted to observe the language function of the cerebellum and other structures typically not involved in the canonical language network (which is entirely cortical) using these language localizers. A study on the cerebellum's connection to language revealed that certain sections of the cerebellum respond robustly to language and even play a part in understanding language as well (Casto *et al*., 2025*).* This suggests that broader regions may have language functions than previously thought and this is an active area of research.

Language Network:

Language localization tasks are a useful tool that allows researchers/neuroscientists to pinpoint multifunctional areas of the brain, such as the posterior temporal cortex and the inferior frontal gyrus that engage in multiple cognitive functions, as well as language-specific areas such as Broca's Area (located in the triangular part of the inferior frontal gyrus) and Wernicke's Area (mid-anterior superior temporal gyrus) that are involved in language processing specifically (Figure 2). Together, these regions along with others make up the *language network*. The language network's main purpose is to transform visual and auditory information into something the brain can understand and draw inferences off of. Furthermore, language localization has been used to isolate individually specific language regions given that the specific anatomy and functional responses may differ from person to person, generating individualized language networks.

The language network is composed of subregions of the frontal and temporal lobes and is thought to allow us to help understand and generate language regardless of its form (spoken or written) (Figure 2B). While Broca's Area and Wernicke's Area have the highest response in language localizers (Blank *et al.*, 2016), all of the regions highlighted in Figure 2A show greater activation (as measured by BOLD signal in the fMRI) to language tasks regardless of medium (listening versus reading; see purple bars in Fig. 2A) as compared to other higher-order cognitive processes such as speech perception, music, theory of mind, etc. (see lower magnitude in non-purple bars of Figure). While responses are shown as the change in the BOLD signal, these effects hold regardless of imaging method and have been shown using electrophysiology (Federenko *et al.,* 2016). Furthermore, remarkably, the language network is incredibly consistent in its location across people (see Figure 4) and across different languages. Malik-Moraleda *et al.*, (2022) demonstrated that the network topology is consistent across 45 different languages from all different language families.

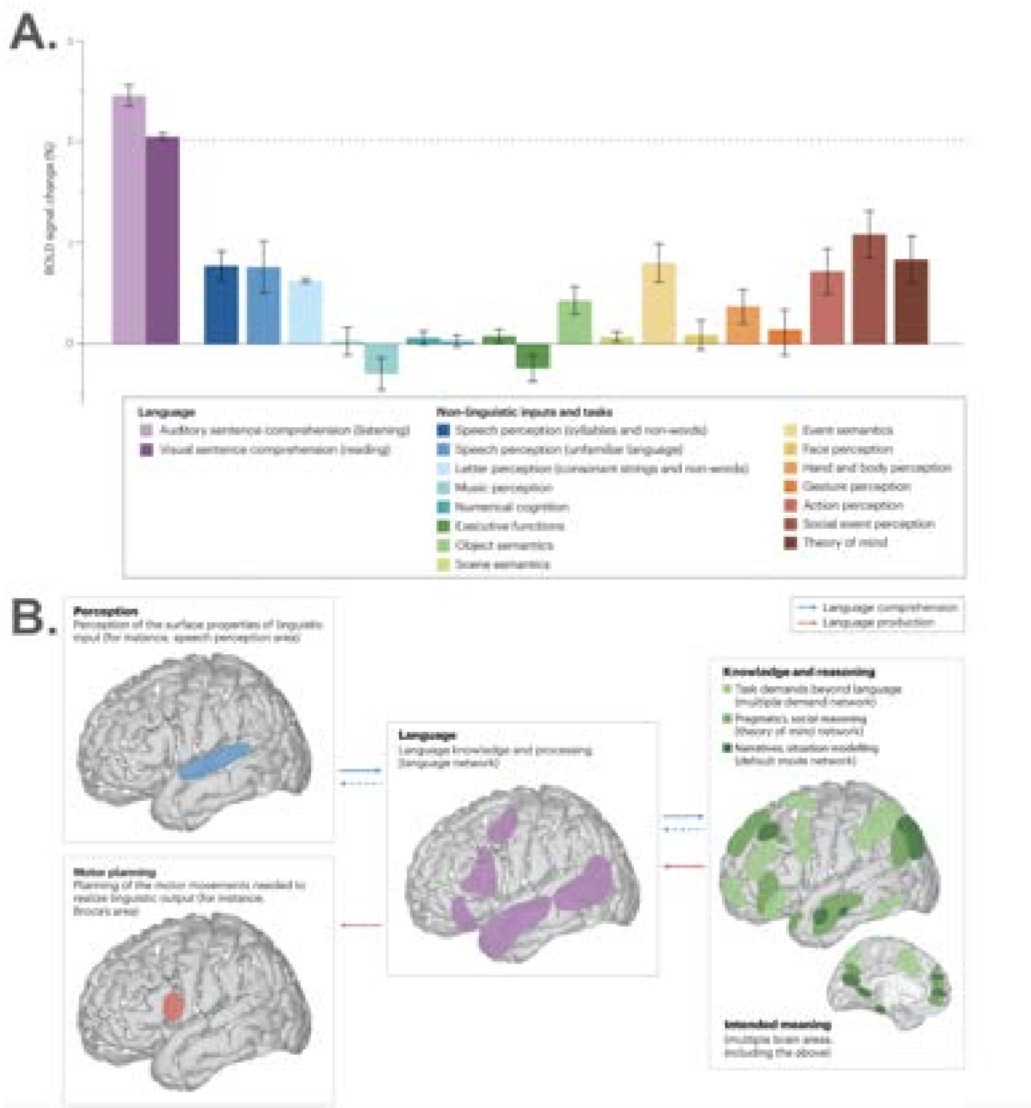

Figure 2: The language network. *A.* Regions involved in the language network respond more to language tasks than related non-linguistic tasks. *B.* Language network functions the specific regions associated with these functions. "Perception" highlights the parts of the temporal lobe dedicated to the initial perception of the language. "Language" highlights parts of the frontal, temporal, and occipital lobes (i.e. Broca's & Wernicke's Areas) that are responsible for understanding the perception and using the language. "Knowledge and Reasoning" shows the regions of the brain that assist in developing complex reasoning based on the information gathered from the areas in B. "Motor Planning" is the part of the motor cortex responsible for creating the motor movements necessary to speak. Adapted from Fedorenko, Ivanova & Regev (2024).

There is some functional specialization even within this network. For example, some regions are involved in lexical processing (focuses on specific words and understanding them) while others are involved in syntactic processing (focuses on grammar and syntax). Perceptual and motor areas process surface features of linguistic signals (speech perception, visual word-recognition, etc). For instance, the Visual Word Form Area (VWFA), typically left lateralized and in the fusiform gyrus, is thought to be responsible for processing written words to help understand their meaning. Despite being a visual region, it shows greater activation for words as compared to non-words *(*Price *et a*l., 1996; Cohen & Dehaene, 2004; Hillis *et al*., 2005*)*. Similarly, the Auditory Word Form Area (AWFA), located in the left superior temporal gyrus, is responsible for processing spoken words and understanding their meaning (Damera *et al*., 2023*)*. These two regions allow the brain to convert information from one form to another, without which the language system would not function properly.

As illustrated in Figure 2, non-language network regions help us gain deeper and more comprehensive understandings of language. These regions belong to higher-level cognitive networks such as the Theory of Mind Network (ToM), the Multiple Demand Network (MD), and the Default Mode Network help to produce complex reasoning (Federenko & Varley, 2016*)*. For context, the MD supports attention, working memory and executive control; the ToM helps to generate figurative meaning, inferences and a point of view (POV); and the Default Mode integrates information across longer timescales, and works with the Language Network to form a fluid narrative (Yeshurun *et al*. 2021). The language network works with these other networks to help develop our understanding of the world, increasing its need to have regions throughout the brain. These different networks and their functions are visualized in Figure 3; we recommend that the reader compares the regions highlighted between Figures 2 and 3.

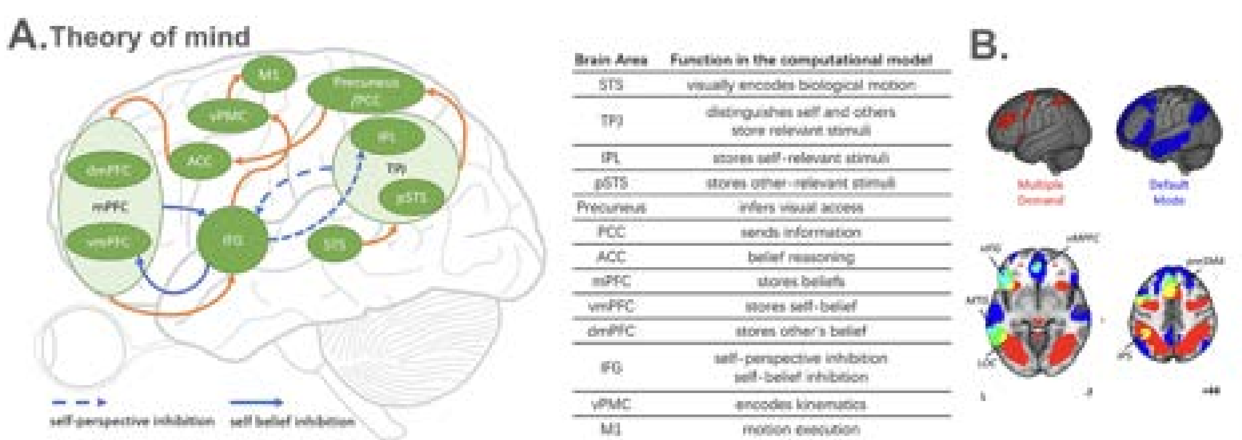

Figure 3: Non-language networks that support language function. The figure details the parts of the three higher-level networks. In A, the TOM Network is modeled, showing the step by step process of higher-order thinking. In B, the Multiple Demand Network and Default Mode are shown, with the brain regions involved highlighted in red, green and blue. Notably, some regions of the DMN overlap with the TOM. Adapted from Zeng *et a*l., 2020 for A; Davey *et al*., 2016 for B.

It is worth noting that defining the language network is an active area of research and neuroscientists continue to argue over it (Aliko *et al.*, 2023). The debate centers on whether linguistic functions are localized to traditional language areas, or distributed across the brain. While localizationist theories argue that regions outside these language areas serve non-linguistic functions, distributed accounts suggest that sensorimotor and other domains are integral to how words—and language more broadly—are represented in the brain.

Regions beyond traditional “language areas” actively contribute to speech perception, semantic processing, and the understanding of pragmatics and syntax and a broader complex understanding. One proposed reconciliation is the core–periphery model, in which traditional language regions form the core while peripheral areas accommodate the flexibility and variability needed for language production and comprehension. Importantly, neuroimaging has shown that thinking about language as a distributed system offers a better explanation for the complex patterns of language breakdown rather than a left-hemisphere “language center”.

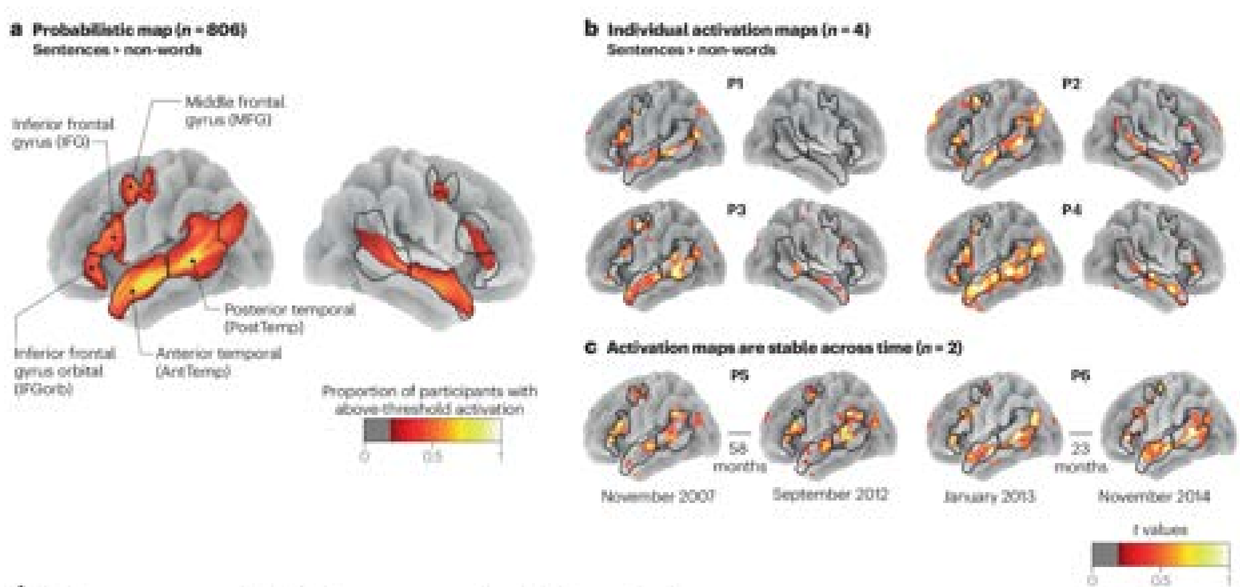

Figure 4: Language network is relatively consistent across people and time. In A it is seen how key areas are activated from sentences versus non-words overall. In B and C, individual brain activations are shown. Adapted from Evelina Fedorenko *et al*. 2024.

Section 3: Linguistic Deficits

The distributed nature of language networks becomes even clearer when examining the impact of aphasia, where damage to different regions produces varied deficits that cannot be explained by classical lateralization theories alone. When these regions are damaged, it can lead to extensive linguistic deficits. One of the most common reasons for brain damage is a stroke. To provide some background, a stroke occurs when blood flow is disrupted to a part of the brain, resulting in tissue death and brain damage. In particular, an ischemic stroke occurs when there is a blockage (blood clot or narrow artery) that prevents blood from getting to a particular part of the brain. Ischemic strokes are either caused by an endothelial cell dysfunction (inflamed inner lining of an artery), by an embolism (a clot lodges itself in a narrow artery), or by a shock (leads to reduced blood flow in the body). About two thirds of stroke patients are left with some form of brain damage and are in need of rehabilitation (Oakland Medical Center). Problems can range from struggles with motor control, behavioral changes, and linguistic challenges.

Aphasia, a disorder of language expression and comprehension, is one of the most common linguistic challenges following a stroke, with roughly one-third of stroke patients developing the condition (Grönberg et al., 2022). Common communication difficulties in aphasia include difficulty creating sentences, using incorrect words, repeating words or phrases, misunderstanding others, reading and writing impairments, and challenges in expressing complex thoughts. Importantly, these language-based deficits are distinct from dysarthria, a motor speech disorder caused by problems with the muscles used for speaking, which often results in slurred or slow speech. The key distinction is that aphasias affect what you want to say, whereas dysarthria impacts how you physically produce speech. For example, someone with dysarthria may know exactly what they want to say but struggle to articulate it clearly, while someone with aphasia may have intact speech muscles yet struggle to access or comprehend words. These two linguistic disorders demonstrate how the language network is composed of many parts, each of which provides a variety of functions. The following section articulates the wide variety of aphasias in order to demonstrate how many brain regions take part in the language system and when one is taken away, the brain loses a critical function.

Different types of aphasias:

Broca's Aphasia occurs when the stroke has damaged Broca's Area, located in the left inferior frontal gyrus. Broca's Aphasia primarily affects the patient's ability to express their thoughts or ideas *through speech*. Broca's Aphasia does not damage their *understanding* of language; it damages their ability to produce coherent speech. In addition to difficulty producing coherent speech, Broca's Aphasia damages the person's ability to repeat things they read or hear (see Table 1 below).

Wernicke's Aphasia occurs when there is damage to Wernicke's Area, located in the left posterior superior temporal gyrus. Wernicke's Aphasia results in the patient's difficulty comprehending speech. Individuals with this particular type of aphasia can produce speech; however, it will be unintelligible, and they will not be able to understand how the words should be used. They are able to talk, gesture freely, and produce sentences of decent length; in other words, they are able to speak fluently. However, they will not understand what they are saying, and their words will carry no meaning. Wernicke's Aphasia prevents people from reading, being able to comprehend what they are reading, and repeat what they've read/heard.

Conduction Aphasia occurs when the arcuate fasciculus– the neural pathway connecting Broca's Area to Wernike's Area– is damaged. Therefore, the two regions can no longer communicate with one another. Thus, patients retain both fluent speech production and comprehension but are unable to use the two together to repeat words they read/hear (see Figure 5 below).

Transcortical aphasias impact regions adjacent to, but not directly involving, the primary language areas. For instance,**Transcortical Motor Aphasia** damages a part of the motor cortex near Broca's Area. Because it is so close to Broca's Area, this type of aphasia damages an individual's ability to produce fluent speech. In comparison, **Transcortical Sensory Aphasia** damages a part of the somatosensory cortex near Wernicke's Area. This damages an individual's ability to understand speech and comprehend what they are hearing. **Transcortical Mixed Aphasia** damages the areas near Broca's and Wernicke's Areas, which results in a loss of the ability to comprehend and produce fluent speech. However, since none of the Transcortical Aphasias damage Broca's Area, Wernicke's Area, or the arcuate fasciculus, individuals with any of the Transcortical Aphasias retain the ability to repeat what they read/hear.

Global Aphasia combines all of the types of aphasia listed above; it is where the stroke has damaged all of the parts of the brain discussed above (i.e., Broca's Area, Wernicke's Area, arcuate fasciculus, and areas near Broca's and Wernicke's). Individuals with this type of aphasia experience profound deficits and are unable to comprehend speech, produce fluent sentences, or repeat anything.

Aphasia	Fluency	Comprehension	Repetition
Broca (expressive)	No	Yes	No
Wernicke (receptive)	Yes	No	No
Conduction	Yes	Yes	No
Global	No	No	No
Transcortical motor	No	Yes	Yes
Transcortical sensory	Yes	No	Yes
Transcortical mixed	No	No	Yes

Table 1*: Aphasia types and their functional compromises.* The table indicates the different difficulties faced by those with different types of aphasias. Fluency refers to uninterrupted and effortful speech. Comprehension refers to the ability to understand language. Repetition refers to the ability to grasp/understand the phrase heard and repeat it accurately. Adapted from https://nursingcecentral.com/lessons/aphasia-after-stroke/

Aphasia Research:

The previous section highlighted some of the more common aphasias as well as the particular brain region they are tied to. However, there are more regions in which stroke damage can lead to linguistic deficits, and ignoring such areas can prevent doctors from accurately diagnosing the condition, keeping the patient from receiving proper care. One such region is the thalamus; a region typically associated with the relaying of information to cortical areas and senses(except olfaction). Nevertheless, thalamic aphasia does in fact exist, disproving the ideology that language is primarily isolated in certain parts of the left frontal and left temporal lobes. After conducting fMRI and MRI scans of individuals with thalamic aphasia and conducting language assessments, it was found that the thalamus is responsible for some lexical-semantic function (Fritsch, Rangus & Nolte, 2022). The thalamus predominantly plays a role in lexical-semantic retrieval and higher-order language function, which is why those with thalamic aphasia lose these functions. Also, as the thalamus is responsible for relaying information throughout the cerebral cortex, once it is damaged it results in the functional decoupling of regions in the language network. This impacts the network's speed and efficiency, therefore diminishing linguistic function.

In addition to the thalamus, researchers have also found linguistic functions tied to the cerebellum which is typically associated with implicit memory functions. Individuals with cerebellar aphasia experience difficulty in word retrieval, phonology, semantics, and syntax. The most frequently occurring errors were semantic paraphasias, circumlocutions and anomias (Satoer *et al*., 2024). The study conducted by Satoer *et al*., 2024 also revealed that the cerebellum appears to interact with cortico-subcortical language areas. This suggests that the cerebellum does have certain sections dedicated to language function, meaning that it is a region of the language network.

The language network's expansive nature doesn't just explain unique types of aphasias; it also provides an explanation to the aphasia recovery process. According to Turkeltaub *et al*., 2025, aphasia patients have an active right hemisphere compared to healthy individuals. Some regions in the right hemisphere that were slightly involved in language for the healthy controls were far more active in the brains with a left-hemispheric aphasia. The study revealed that many people with linguistic deficits do tend to use their right hemisphere much more in order to help with naming and reading words. However, over-reliance on the right hemisphere (particularly the right arcuate fasciculus) resulted in poorer naming recovery (Keser *et al*., 2019). While initially usage of right hemispheric homologous pathways assist in post-stroke aphasia recovery in categories such as verbal fluency and speech production, over-reliance on it resulted in poorer naming recovery. These findings on the right hemisphere's impact on aphasia recovery suggest that the language network is not just sequestered to the left hemisphere; rather, it is constantly changing and expanding into new regions.

Overall, the patterns of language impairment highlight the role of connectivity across networks, demonstrating that language function is much more versatile than ever taught before and that these are important facts that doctors need to take into account when dealing with these conditions.

Section 4: Evolution of bilingual brain research.

This versatility is further illustrated in the bilingual brain, where the second language allows the network to become even more resilient. Some of the most active and interesting work in this space investigates how it impacts speakers of multiple languages *and,* bidirectionally, how speaking multiple languages may aid in recovery.

Until very recently, research on bilingualism was inconclusive. Some studies localized bilingual language processing to the left-hemisphere regions, while others found more bilateral activation across the brain. Many of the older studies (Scoresby-Jackson, 1867; Pitres, 1895) had one thing in common–they all seemed to believe that the age of acquisition of the second language (L2) was the greatest contributing factor in determining how the bilingual brain functions. However, recent studies (Sebastian *et al*., 2011; Cargnelutti *et al*., 2019) have determined that L2 proficiency and the amount of exposure a person has to their L2 is a stronger predictor of what their brain may look like. If a person has a higher L2 proficiency, they will show similar activation patterns as their L1 (mainly in the left frontal area), but they will also have some dispersed activation in some parts of the right hemisphere (Sebastian *et al*., 2011). If a person has a lower L2 proficiency, they will have smaller and distributed activation across both hemispheres. Many researchers also found that, despite similar language network topology, each language represents itself slightly differently in the brain–so the results may vary based on what languages the bilinguals are fluent in (CITE). For instance, those that are fluent in a tonal language, such as Mandarin or Cantonese, tend to use regions in the right hemisphere a lot more than those that are fluent in a non-tonal language (Fan *et al*., 2011). The experiment conducted by Fan *et al*. also concluded that Mandarin-Cantonese bilinguals have stronger brain connectivity in the brain network related to language control, inhibition, phonological and semantic processing, and memory retrieval compared to Mandarin monolinguals. They suggest that this distinction is because bilingualism activates areas that are adjacent to regions that control those functions.

One of the most essential findings made by researchers is that the bilingual brain is a complex neural network that can vary across individuals; it is not two monolinguals in one mind (Grosjean, 1989). When a multilingual person is exposed to one of their languages (in any form), the other languages are also activated. This is known as the Bilingual Interactive Activation (BIA) model and it also explains why cross-language intrusions exist. For instance, in Spanish "embarazada” means pregnant. However, “embarazada” happens to look and sound a lot like the English word "embarrassed". When an English-Spanish bilingual sees that word, both the English and the Spanish meanings start competing for recognition. In this case, the Inhibitory Control (IC) Mode comes on and inhibits the irrelevant word. Certain regions are thought to mediate the IC Mode, namely dlPFC or dorsolateral PFC (inhibition, cognitive control), anterior cingulate cortex (conflict monitoring), and left inferior frontal gyrus (inhibition of language you do not want, support of language you do want).

As a person increases their L2 proficiency, inhibitory control begins to become automatic and they learn to block out the irrelevant language. Some interesting evidence for these complex multi-regional interactions between these inhibitory control regions and language regions comes from the RRT(patient name) case study (Calabria *et al*., 2014). RRT experienced severe subcortical and cerebellar damage due to the onset of multiple sclerosis. He struggled with cross-language intrusions (especially while speaking Catalan, his dominant language), pathological language switching, and pathological language mixing. At its core, this meant that he was having trouble with inhibitory control. When he was tested on Executive Control tasks, he was found to be well below average brain levels. This case highlights the crucial independence between language control mechanisms and broader executive function.

Outside of inhibitory control, as one would expect, whenever a bilingual individual sustains some form of brain damage to the core language areas, they still experience some sort of aphasia. However, there is evidence to suggest that being bilingual may aid the recovery. After some form of speech-language therapy, bilinguals are found to have a decreased latency time compared to monolinguals (De Letter *et al*., 2021). This is likely due to the bilingual brain using higher-order cognitive control to select, maintain, and switch between two languages (Green, 1998). If preserved post-stroke, this network may positively influence L2 proficiency. When bilingual aphasic patients begin therapy, the preserved higher-order network creates a cognitive reserve (something monolinguals do not have), suggesting higher accuracy in cognitive functions and a more rapid recovery of linguistic abilities (De Letter *et al*., 2021).

Nevertheless, the extent of the bilingual advantage and the details pertaining to it are not fully understood. More research is needed to examine how factors such as Age of Acquisition, L2 proficiency, and age influence recovery outcomes. Such work would provide a more nuanced outlook on the role of bilingualism in aphasia rehabilitation, allowing for greater advances in the treatment sector. By showing the nuanced nature of a multilingual brain, bilingualism has demonstrated how distributed and dynamic the language network is.

Conclusion:
Altogether, evidence from classical studies, neuroimaging, aphasia and bilingualism converge to form a fuller picture of a distributed language network, moving beyond lateralization of language function to a single region. The research proves how versatile the language network is and how many sub-parts it's made up of. Aphasia research highlights how vital each of these regions is to the network, while studies of bilingualism highlight how experience with multiple languages strengthen the overall network and even facilitate recovery after damage. This knowledge can assist doctors in accurately locating and diagnosing the issue as they will not be restrained by a limited localized view. Reviewing said studies can help to broaden their minds and associate the symptoms with a condition, allowing for better treatment. Although a lot of progress has been made, research into the many parts and functions of the language network is still ongoing. Future work should continue to refine how language localizers are applied across different regions of the brain and examine how other factors, such as the age of acquisition and the specific languages spoken, shape bilingual brain organization, as well as how all of these factors impact patient treatment for a neurological condition. All in all, cognitive neuroscience regarding language has come far, but still has a long way to go.

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