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Language Processing in the Human Brain: The Role of the Left and Right Sides

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Abstract

This academic paper elucidates that cognitive functioning in any domain — memory, attention, abstract reasoning, language, etc. — cannot be uniquely correlated to either the left or right cerebral hemispheres.

These complex actions stem from both hemispheres of the brain working together and in coordination with one another as a team, emphasizing their relationship. The localization of language has been the subject of decades of research, and the aim of this extensive article is to identify not only the different distribution of language across the two hemispheres but also their respective anatomical locales. More on this integrative view of connectionism will be discussed here, as it provides a very different and opposes the classical localizationist paradigm, wherein it has further divided many brain regions into their respective and exclusive functions and was thus supported by this convincing and comprehensive study.

This study seeks to shed light on essential concepts related to a host of language features associated with several interconnected brain regions. We hope that this article will provide a significant contribution to the ongoing discussions within the field of cognitive neuroscience and provide insight into our understanding of language processing and its brain bases.

Keywords: Left and Right Hemispheres, Frontal Lobe, Wada Test, Linguistics, Human Cerebrum, Connectionism, Localizationism, Lateralization.

1. Introduction

This research examines the precise localization of language in the human brain. It aims to investigate the specific locations of language functions within the human brain. Additionally, it examines the roles of functions in the left or right hemispheres.

The comprehensive exploration of advanced psycholinguistics, with a concentrated focus on the intriguing field of Neurolinguistics, is conventionally segmented into two significant and noteworthy schools of thought, which are outlined as follows: 1. The Localization School, often referred to as the Localists. 2. The Connection School, commonly known as the Holists (Alduais et al., 2022) (Godfroid & Hopp, 2023).

Throughout the 19th century, there were key advocates of the localization viewpoint, with the illustrious surgeon Paul Broca standing out as one of the most prominent and impactful figures in the discourse. He firmly believed that the human brain's large and complex structure could be divided into two independent and different hemispheres, with the left hemisphere being found to be primarily responsible for a number of important linguistic processes. The crucial role of the left hemisphere in language processing — the mechanisms required to yield rich and successful interaction (Ullman, 2020) — was a sharply evident contribution here.

The important premise of localizationism was already solidified and corroborated by many studies that showed strong left hemisphere activation when processing aspects of language, specifically syntax and semantics (Graessner et al., 2021).

In addition to these enlightening discoveries, localizationists also reversed course, demonstrating that some parts of the left hemisphere played a greater and more essential part in people's overall language skills. The study showed that language function heavily depended on certain regions of the outer cortical surface's central ripple zone (Caucheteux & King, 2022).

It is interesting to take note that damage outside the left hemisphere rarely resulted in any significant and often imperceptible impact on individuals' general language abilities and performances (Gajardo-Vidal et al. 2021).

On the other hand, the Connectionism school also called the Holists, argued vigorously that the localization of function does not come close to doing justice to the vast complexity of isolating specific language functions. Herbet & Duffau (2020) affirm that these complex processes are mainly enabled by the highly composite networks that are dominant in the topological structure of the human brain. This all-encompassing method emphasizes the need of comprehending the fundamental connections between different brain regions. It focuses primarily on employing linguistic methodologies while also relying heavily on cognitive competencies and capabilities, which encompass essential mental faculties, crucial abstract reasoning skills, and the necessary attentional focus required for a variety of cognitive tasks and endeavors (Perich & Rajan, 2020).

1.1 Localizationism:

In a similar vein, T.W. Deacon addresses this inquiry in his work, "The Symbolic Species" (pp. 306-8, 1997), asking: "How should different sections of the human brain be prepared to engage with syntactical and grammatical information processing?" He posits that, much like uncomplicated word association processes, the answer to this question is likely contingent upon processing demands rather than the existence of a dedicated grammar processing center. The execution of syntactic procedures and grammatical evaluations may encompass a variety of paradigmatic and syntagmatic processes, which can vary significantly from one language to another.

Localization, as articulated by localists, serves as a foundational hypothesis for examining the relationship between the human brain and language. This perspective

posits that distinct regions of the brain contribute to specific functions associated with language (John Field, 2003: 151-152).

1.2 Connectionism:

The Connection (holists) represents a domain within the science of epistemology that seeks to accurately elucidate human cognitive abilities through the utilization of artificial neural networks, commonly referred to as nerve networks (Russo et al., 2024).

These neural networks represent simplified models of the complete human brain, consisting of numerous nerve cells, or enzymatic units, in conjunction with weights that define the strength of the connections among these cells (Montesinos et al.2022).

"Experiments conducted on models of this nature have demonstrated a capacity to acquire skills including facial recognition, reading, and the identification of basic grammatical structures." These weights illustrate the influence of the synaptic connection between the two neurons that interconnect one neuron with another (Azimova & Solidjonov, 2023).

2. Neurobiological Basis of Language Processing

The processing of language engages a distributed network of connectivity of specific regions of the brain. In discovering more about how the cooperation of various regions of the brain makes language processing fluid and effortless, the availability of imaging techniques has greatly contributed. In terms of systematic measures of electrical and hemodynamic changes of the brain associated with language processing events, the improvement occurred in the form of event-related potentials and functional magnetic resonance imaging. In functional neuroimaging research, these measures are frequently used to provide hard evidence on the organization of brain regions into distributed neural networks, as well as to pinpoint the temporal course of the different stages of language processing (Jackson, 2021).

The rapid advancement of neuroimaging, in combination with growing informatics skills, has greatly contributed to what can rightfully be called the 'neurolinguistic revolution.' The term refers to the recent ever quicker development, methodological advances, and successful contributions of neuroscientific research to the field of linguistics. The revolution is characterized by a two-sided impact on interdisciplinarity, coming from the side of cognitive neuroscience and from the domain to which it is related, in this case, linguistics. The relationship between these two domains, in terms of the impact of brain research on linguistics, has assumed many forms and has been addressed from a range of different perspectives (Nassoba & Samanik, 2022).

2.1. Broca's Area and Wernicke's Area:

The title of this topic explicitly suggests that it addresses the primary regions of the brain associated with language functions. Consequently, it encompasses both Broca's Area and Wernicke's Area. The former, Broca's Area, is especially pivotal in the articulation of language. This region is tasked with language production, encompassing both verbal and written communication. It is significantly advanced in the left hemisphere and is situated within the motor association cortex, immediately preceding the area of the brain responsible for the coordination of the mouth and larynx (Sprung-Much et al.2022).

By comparison, Wernicke's Area, the second area, is responsible for understanding language. That is why it is said to be concerned with the comprehension of speech and writing. Furthermore, Wernicke's Area extends properties necessary for language, such as understanding spoken and written language, producing connected speech, solving problems, or remembering complex commands. Just like other types of brain functions, understanding human language also entails many specialized brain areas (Rutten, 2022).

2.2. Neural Pathways Involved in Language Processing:

The main function of the pathways that connect Broca's and Wernicke's areas is to support communication between the auditory and motor areas. These pathways allow the language system involved to support the perceived sounds associated with language generation in Broca's area. Connections are mainly formed between the inferior parietal lobe and the frontal lobe via the superior longitudinal fasciculus, the extreme capsule fiber system, and the arcuate fasciculus. Biologically, the control of motor function is through two neural pathways called corticospinal and corticobulbar tracts, which run between the cerebral cortex and the brainstem or spinal cord. There is a rich somatotopic organization, with related face areas entering the pons and involving the pyramidal tracts (Unger et al.2021).

The arcuate fasciculus is a vertical association bundle of long fibers interconnecting the frontal lobe and the temporal lobe of the human brain and a major part of the ventral language pathway. The arcuate fasciculus is involved in several major language functions, especially related to language input-output modalities. Besides that, there are neural tracts that support the connections between Wernicke's area and the entire neocortex, especially posterior temporoparietal regions and other areas that support language functions (Becker et al.2022).

3. Divisions of the Human Brain

In infants, the components of the brain exhibit a remarkable degree of flexibility and smoothness. In instances where any area sustains damage, the brain's elements possess the capacity to eventually reallocate the functions of the affected regions to other areas that remain intact. As the individual matures over time, each sector of the human brain increasingly develops specialization. This specialization enables distinct regions to assume particular cognitive responsibilities, thereby improving the overall efficiency and adaptability of the brain (Elizabeth A. Rider, Carol K. Sigelman, 2017: 510).

The human brain is composed of four primary lobes: the frontal, temporal, parietal, and occipital lobes. Each of these lobes is integral to a variety of cognitive functions, encompassing reasoning, language processing, sensory perception, and visual interpretation. The frontal lobe is essential for performing higher-order activities including decision-making and problem-solving. The temporal lobe is essential for language comprehension and memory formation, underscoring the intricate relationship between the brain's anatomical elements and linguistic ability, along with the modulation of automatic emotional reactions. The parietal lobe mainly enables the integration of visual information, somatosensory, as well as somatospatial information. Where the occipital is responsible for the reception and processing of visual information, the temporal one controls language, auditory perception, and long-term memory (Schwaring & MacDonald, 2020).

4. Lateralization

The idea of lateralization in the human brain suggests that only one of the hemispheres is responsible for or generates specific language functions. In most people, the left hemisphere is predominantly involved in language. Recent discoveries show that the left hemisphere is mainly involved in language production and comprehension, whereas the right hemisphere might play an important role in the interpretation of emotional and contextual aspects of language. Such a nuanced perspective on lateralization demonstrates that the subdivision of linguistic action in the brain is much more complex than merely being localized in one hemisphere, as both are crucial for a well-rounded understanding of communication. This finding highlights the importance of adopting a more integrated approach to the study of language functions. This also indicates that language on its own is not a cognitive process, rather, it's intertwined with emotion and social processes (D. V. M. Bishop, Dorothy V. M. Bishop, 1990: 136).

An obviously related volume in this sense is T.W. Deacon's "The Symbolic Species" (pp. 311-15, 1997), which discusses the relevance of lateralization for cognitive processes and implications for language processing throughout the brain. He posits that "as a result, the well-regarded complementary pair of mental functions can be associated with a brain exhibiting differing functions on contrasting sides. Since the mid-19th century, there has been an ongoing debate among psychologists and medical professionals regarding whether the left hemisphere is characterized as female while the right hemisphere is deemed male; whether the right side is non-verbal while the left is verbal; whether the right hemisphere is associated with spatial abilities while the left is linked to linguistic skills; whether the right side is irrational while the left exhibits rationality. Additionally, the right is seen as undifferentiated while the left is differentiated; the right is considered holistic while the left is localized; the right is related to negative emotions while the left pertains to positive emotions; the right side relates to the id and the left to the ego; the right is recognized as subordinate while the left is dominant; and even the right is aligned with primate cognition while the left is aligned with human cognition, to mention just a few significant dichotomies." These distinctions illuminate the intricate nature of brain lateralization, indicating that each hemisphere not only engages in distinct functions but also plays a role in a comprehensive cognitive framework. A thorough understanding of these differences is imperative for investigating how language processing may differ among individuals and may provide valuable insights into atypical brain functions observed in disorders such as dyslexia and aphasia (John Field, 2003: 153-55).

Indeed, the considerable lateralization of various linguistic functions to the left hemisphere of the vast majority of human brains has provided substantial support for the hypothesis suggesting that such lateralization may have been a prerequisite for the development of language.

Numerous experts in the field contend that this pronounced lateral distinction constitutes a central, fundamental framework of logical language. The compelling approximation involves the endeavor to establish the most systematic method of categorizing the human brain into two primary complementary epistemic mechanisms. Lateralization is not merely an evolutionary term akin to adaptation throughout the entirety of human history; rather, it is pertinent to reducing or mitigating any neurological "inability to decide" regarding the appropriate course of action (Olulade et al.2020).

5. Evaluations and Rationales for Lateralization

Research indicates that the lateralization of brain function is often influenced by the extent of cerebral damage experienced by patients. Specifically, when the left hemisphere sustains injury due to circumstances such as a vehicular accident, invasive surgical procedures, or a cerebral infarction, it frequently results in significant repercussions for the individual's linguistic capabilities. The relationship between language functions and the left hemisphere has been substantiated through various assessments: (John Field, 2003: 97).

1. Juhn Wada Tests:

The Wada test, named after J. A. Wada, serves as a significant evaluation method within neurology. This test demonstrates that in certain patients, the ability to utilize language is temporarily suppressed when sodium amytal is injected into a vessel, thereby inhibiting the functions associated with either the right or left hemisphere of the brain. Through his observations, Wada has determined that the left hemisphere exhibits a greater degree of deactivation compared to the right hemisphere during this process.

2. Dichotic Listening:

In the context of dichotic listening, verbal transmission of information between individuals is notably influenced by the right ear. When multiple auditory stimuli

are presented simultaneously to both ears, it is typically found that the right ear has a predominant role in processing speech-related messages.

3. Commissurotomy:

A commissurotomy is a type of surgical operation used for some patients with extreme forms of epilepsy. This surgery consists of dividing the corpus callosum, the bridge between the right and left hemispheres of your brain, which has undergone strong episodes of epilepsy hard to control. After undergoing this procedure, patients show the ability to verbally identify objects presented to the right visual field, suggestive of left hemisphere dominance, yet the ability to name objects in the left visual field is lost (Qadri et al., 2021).

Conclusion

Human body functions are somewhat symmetrical; the human body is equipped with two eyes, two ears, and two hands. This bilateral structure emphasizes that many bodily functions are interdependent and take place simultaneously. Even the brain itself can be said to exist in this kind of duality, as the left and right hemispheres work in concert to control language functions within different branches of science, such as phonology, morphology, syntax, and semantics. These cognitive functions differ between people and are derived from the analysis-by-synthesis model that enables thoughts to be expressed in both our receptive language skills and productive language skills. In terms of language proficiency, writing and speaking are categorized as productive language skills; while listening and reading are classified as receptive skills. Consequently, the brain plays a pivotal role in harmonizing the processes of language production, perception, and comprehension. It is a common misconception to attribute all language functions exclusively to the left hemisphere; in fact, the right hemisphere is neither rudimentary nor silent. Both hemispheres collaborate, sharing complementary and essential functions. This synergy is indicative of an evolved balance of function patterns, suggesting that the

human brain has the capacity to expand in order to foster innovative thought and creativity, often referred to as "thinking outside the box." Conversely, there are instances where the brain may experience contraction, leading to a reduction in innovative capacity. Furthermore, I would like to present a personal perspective on the definition of the human brain. It can be characterized as a complex mass of enzymes, or nerve cells, which I believe is the most succinct scientific description available. Each signal traverses from one region to another within the brain, guided by a three-dimensional structure that operates on three foundational principles:

1) the cells transmit warnings through mutual interaction; 2) they distinguish between beneficial and harmful signals; and 3) they reroute harmful signals to the periphery for neglect. This network of enzymes systematically organizes the transmission of signals throughout the human brain.

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