THE ANATOMY OF LANGUAGE IN HUMAN BRAIN: A REVIEW

Author's Name: Aneesa Farooq

Affiliation: Research Scholar, Department of Linguistics, University of Kashmir, Shri Nagar, Jammu & Kashmir, India

DOI No. – 08.2020-25662434

Abstract

Language is the complex phenomena that activates almost every region of the brain. During the 19th century, observational and the autopsy driven studies have prompted many researchers to postulate modular representation of language. These modular representations are outdated because it does not represent the functional neural networks of language; however, they are still useful as they provide the structural perspectives. In order to understand the neural networks of the linguistic functioning, neurophysiology has revealed specific cortical brain regions. The connection between these cortical regions are involved in the organization of linguistic behavior. Moreover, these studies can have many implications to study the functional processes in both normal and abnormal brains. This paper is an attempt to describe how the different areas are involved in processing the different linguistic capabilities. All these capabilities like phonology, syntax, semantics etc. invoke various cortical regions. Data from both the lesion and neuro-functional works are taken into consideration to analyse the anatomy that supports the language. As a result, activation for the phonological processes is highly reported at planum temporale (pPT), planum porale (pP), superior temporal gyrus (STg), superior temporal sulcus (STs), primary auditory cortex (PAC); semantic processes at temporo-parietal cortex (TPc), superior temporal lobe (STl), inferior frontal lobe (IFl); and syntactic processes at anterior temporal lobe (ATl), planum temporale (pPT), ventral and dorsal supramarginal gyrus (vSMg), and pars opercularis.

***Keywords**: Language, Phonology, Semantics, Syntax*

INTRODUCTION

Language is a mental phenomenon that is articulated in language behavior. It involves the process of thoughts and the connection of sounds and symbols with a meaningful concept to describe ideas and the external environment. Processing of language follows a particular neural path; the interaction of sensory neural networks and the motor input/output system. Sensory input is processed via auditory, visual or tactile neural pathway. However, motor output is generated via articulation, signing, writing or drawing. All these diverse linguistic processes can be studied through neuroimaging studies.

Language anatomy has been a widely studied topic/area; however, the functional basis of language remains difficult. For more than a century, it was believed that language is located specifically at the two areas (Broca's area and Wernicke's area) on the left hemisphere of the brain. Damage to these areas due to stroke or aging leads to the language loss or aphasia. The advent of new technologies such as magnet resource imagining (MRI), functional magnetic resource imagining (fMRI), magnetoencephalography (MEG), electroencephalography (EEG) leads to a considerable increase in language based studies of the brain. According to the recent studies, language is not specifically localized to some regions or not even to one side of the brain. However, language ability is associated with different areas of the brain. Linguistic neuroanatomy has been studied through a number of perspectives. Some models focused on neural connection in speech perception, whereas others try to focus primarily on memory system of language processing. Still others focused on articulation and comprehension of language (as cited in Friederici, A. D., 2011, pp. 1357).

Of a numerous publications on this area, researchers from neuroimaging studies conclude the areas that are specific to language processing: 98% cases shows Wernicke's area Inferior, 97% of Broca's area, 90% of Supplementary Speech area, 83% Wernicke's area Superior, 82% of Basal Temporal region, 77% of Exner's area and 70% cases show Angular Gyrus.

PHONOLOGICAL REGIONS

The core regions for the acoustic analysis of speech is primary auditory cortex (PAC) located on the temporal lobe bilaterally in heschl's gyrus (HG) (Friederici, A. D., 2011, pp. 1362). Studies found that HG analyses both linguistics and non-linguistics sounds per se. Moreover, areas adjacent to HG are pPT, pP, and the area in the STg at the lateral convexity of the cortex extending to the STs are activated for the acoustic analysis of the speech. pPT or supramarginal gyrus is involved in categorizing the sound and then to send the information to higher order cortical areas. While as pP was found to process the speech perception of phonemes and to differentiate between speech and non-speech sounds. Neuroimaging studies found that the posterior STg processes basic acoustic features of the sound and processes sounds earlier than pP. Furthermore, studies found that deficit in the posterior STg generates word deafness as well as inability in the perception of non-linguistic signals. PAC bilaterally responds to speech sounds and the tonal pitch; right PAC responds to tones and pitches while as left PAC responds to speech sounds. Accordingly, the preceding region deals with supra-segmental features while as the following region deals with perception and recognition of speech sounds (as cited in Friederici, A. D., 2011, pp. 1363).

Several reviews of language anatomy suggests that phonological stage of spoken word recognition activates the neural connection bilaterally at superior temporal lobe which includes STg and STs. In addition to this, some studies have concluded that lesion in superior temporal lobe causes impairment in spoken word recognition nevertheless; such impairments are phonologically mild in nature but are severe in lexicosemantic processing. Wada test and split-brain studies also report that auditory comprehension at word-level is processed at the right hemisphere of the brain where the errors are specifically semantic than phonological.

Planum temporale in the left hemisphere consists of an area Sylvian Parietal Temporale (SPT) which is found to be responsible for the functioning of speech sounds. Some researchers suggest that certain non-speech stimuli also activate the PT. In some neuroimaging studies, result shows that left PT responded better to tonal speech than to speech sounds. PT receives variety of signals, these signals are processed according to the type of information. The versatile nature of PT led some researchers to propose that PT acts as a "computational hub". Thus, the neural connections of temporal cortex area is claimed to be a phonological centre that includes areas like pPT, PSTg, pP, aSTg.

Anterior Superior Temporal Gyrus (aSTg) is bilaterally involved in phonological perception (Price, 2012; as cited in Benjamin et al., 2017, p. 4242) the posterior area of STg that extends to SMg is responsible for phonological retrieval processes. In addition, the lesion studies shows that the damage at the posterior STM and SMg leads to impaired phonological processing (Binder, 2015; as cited in Benjamin et al., 2017, p. 4242). Numerous researches have shown that posterior STs is responsible for the representation of speech sound that carries phonetic information as in normal speech, or spectrally rotated speech. It has been consistently shown in lesion studies that anterior temporal region is responsible for the speech comprehension. Besides that some researchers manipulated psycholinguistic variables to study the phonological networks and concluded that the phonological system is specifically left dominant. However, functional imagining studies and the neuro lesion studies suggests a bilateral organisation.

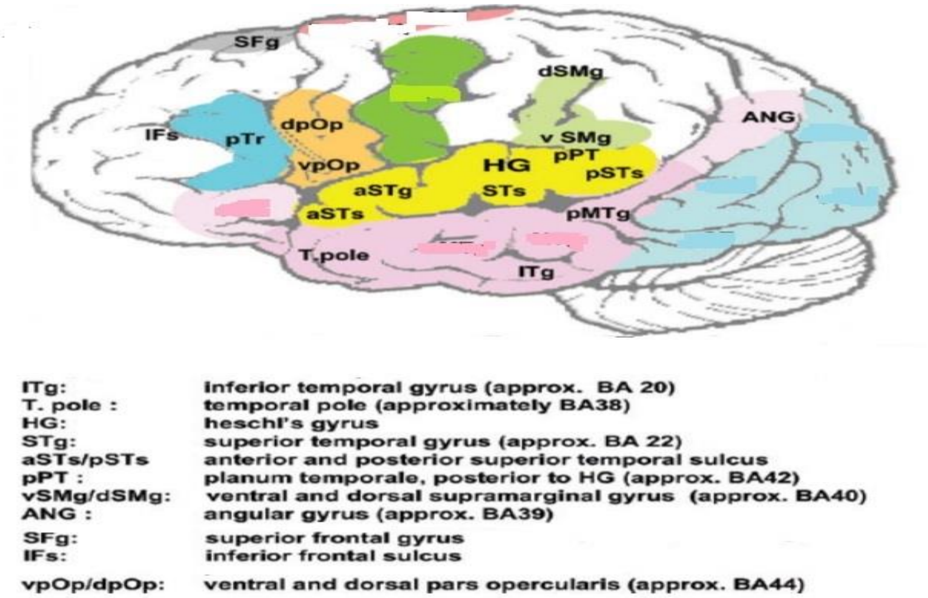

Figure 1: Some architectonic areas of relevance to the present paper as cited in Price, 2010, p.64,

SEMANTIC REGIONS

Based on consensus, conceptual-semantic information is present throughout the cortex. Researchers such as Patterson, Nestor, and Rogers found that the anterior temporal region is an organized semantic hub. Nonetheless, researchers like Caramazza and Mohan states that semantic knowledge specifically evolutional semantic categories like knowledge of animals, food and possible tools is represented in functionally organized neural networks.

Studies report that auditory comprehension deficit is associated with the damage at posterior temporal lobe along with the middle temporal gyrus. In addition, cortical stimulation mapping demonstrated that middle temporal gyrus, superior temporal lobe particularly anterior portion and the inferior frontal lobe is involved in auditory comprehension (Miglioretti and Boatmen; as cited in Hickok, 2009, p. 7).

Clinical studies from the stroke patients acsertained that posterior lateral and inferior temporal lobe are linked to semantic level deficit at word processing (Chertkow et al., 1997; Hart and Gordon 1990; as cited in Hickok, 2009, p. 7). In addition, patients with semantic dementia have degenerative brain cells in the anterior temporal lobe bilaterally which leads to deficit on lexical processing such as naming, comprehension at word level, and semantic association. However, semantic dementia leads to deficit to more than one region including the area that supports memory functions such as bilateral inferior and medial temporal lobe, bilateral caudate nucleus, and right posterior thalamus. Such patients shows deficit not only in accessing auditory semantic knowledge but also in visual semantic inputs which shows that damage is not restricted to one modality instead it damages conceptual semantic knowledge in general. Furthermore, it was stated that inferior and posterior lateral temporal lobe is specifically involved in accessing semantic knowledge from auditory input, whereas the anterior temporal lobe seems to be more involved in processing semantic knowledge across modalities (Peterson et al., 2007; as cited in Hickok, 2009, p.7).

Several investigators suggests that angular gyrus is associated with distributed semantic system that can be accessed by visual and acoustic inputs of the object. Though, lesion and electro-physiological studies reveals that semantic processing occurs in anterior inferior temporal lobe and in the angular gyrus. Damage to the left angular gyrus shows deficit with both written and spoken word comprehension. Several other investigators report that semantic system include several areas of activation at the inferior and middle temporal lobes. Patients with damaged left anterior and inferior temporal region shows extreme loss of semantic knowledge (Hodges et al., 1992; as cited in Price, 2000, p. 350). Similarly, patients with trans cortical aphasia shows damage in the left inferior temporal lobe, posterior inferior parietal lobe , the left thalamus and the white matter connecting these areas. Cortical and sub-cortical studies also indicate semantic knowledge in the left anterior temporal lobe and left parietal cortex.

A review of 120 studies reported by Binder et al (2009, p. 2769) that anterior and posterior left middle temporal gyrus, bilateral anterior temporal lobe, left angular gyrus, posterior cingulate areas are responsible for the semantic processing. Functional neuroimaging studies have also indicated the involvement of posterior middle temporal areas in lexical-semantic processing and the left posterior inferior temporal cortex for the word retrieval. Moreover, Exner's area in the middle frontal gyrus at the posterior extent is activated to produce the written form of words by transforming its phonological representation into motor commands (Roux et al., 2010; as cited in Benjamin et al., 2017, p. 4241).

Neuroscientists reveals that familiar auditory semantic inputs activates a wide range of areas surrounding ventral, anterior, and posterior borders of the perisylvian regions supporting pre-lexical auditory speech processing. These activitions are spreading as a spider web centred on HG. However, these frontal granular areas are associated with cognitive semantics knowledge for language processing. Thus, the semantic activation over a massive distribution suggests that there are many paths of speech perception and comprehension (Rauschecker and Scott, 2009).

The precise location of the activation of semantic processes varies from study to study, as there are specific areas specialised for different types of semantic information. For example, there is more activation in the area of left posterior middle temporal lobe in reading the object names or the actions associated with objects than the names of famous people. However, an area in the anterior inferior temporal lobe is more active in reading the names of famous people than names of objects i.e., it is more active when specific semantic attributes are processed. Studies reveal that left posterior inferior parietal cortex also have some anatomical specialization for the language processing. Activation extends to the angular gyrus and the regions close to the temporal cortex in picture naming tests. Furthermore, dorsal posterior inferior parietal cortex is more active for the semantic judgement of the location of objects in comparison to the judgement on the colour of the objects (Mummery et al., 1998; as cited in Price, 2000. p. 352). Besides the activation in the anterior and posterior middle temporal and posterior parietal cortex, the middle fusiform gyrus (Brodmann's area 20), the left inferior and middle frontal gyri including the anterior part of Broca's area are also activated . The Brodmann's area is more active when pictures or words are viewed or when listening to the names of objects or abstract words. Some of the studies suggest that some parts of inferior frontal lobe are specifically involved in semantic and phonological tasks (Buckner et al. 1995; Fiez 1997; as cited in Price, 2000. p. 353).

The association of the meaning of different words occurs in the anterior ventral inferior frontal region. Activation in the left posterior temporo-parietal cortex including angular gyrus and some regions in the middle and inferior temporal lobe when the meaning of word is accessed. The dorsal posterior inferior frontal cortex is involved in phonemic decision of linguistic processes. Likewise the activation in the anterior portion of Broca's area is involves in generating word association during speech production tasks. However, the anatomical specialisation of these regions is still a matter of debate.

Processing of the input word activates bilateral superior temporal gyri. Left posterior middle temporal, posterior temporo-parietal and anterior inferior temporal regions accesses the different semantic attributes. Activation in the posterior superior and left posterior inferior temporal region are observed when speech output is required. When words or sub-lexical speech is read or repeated (not when pictures are named) activation occurs in the posterior superior temporal sulci. Nevertheless, at the verbal fluency and picture naming tasks, activation is observed at left posterior inferior temporal cortex. The posterior temporo-partietal region bilaterally and the left anterior temporal lobe are involved in semantic processing of several visual and auditory inputs.

SYNTACTIC REGIONS

For decades, Broca's area was considered to be a core of neural basis of syntactic processing for both the production and comprehension. Broca's aphasia often leads to agrammatical speech in which patients are unable to handle or generate grammatical elements such as difficulty to understand complex sentences, reversible passive sentences and sometimes phonemic disintegration. Broca's area was supposed to process the syntactic aspect of language. In contrast, functional neuroimaging studies on normal individuals shows that Broca's area is active when an individual is provided with linguistically complex sentence as compared with simple sentence. However, few studies found that Broca's area is not specifically active for the syntactic analysis of linguistic processes (Mazoyer et al., 1993; as cited in Hickok, 2009, p. 9). The theoretical aspect of studies found that the syntactic processing deficit is either the result of functional disruption of the Broca's area or working memory. The anatomical specialization of Broca's area is still a matter of debate, however one of the neuroimaging studies shows that one portion of the Broca's area supports the syntactic processing via working memory.

It is pertinent to mention that ATL is responsible for processing syntactic computations whereas others claimed that ATL is specifically associated with the combination of semantic processes with the syntactic structures. Still others suggest that this area is responsible for analysing the structured sentences, scrambled sentences, nouns, sequential sounds (Friederici et al., 2000; Humphries et al., 2006; Humphries et al., 2005; Humphries et al., 2001; Mazoyer et al., 1993; Vandenberghe et al., 2002; as cited in Hickok, 2009, p. 4). However, lesion studies analysis that damage to the ATL leads to difficulty in processing the syntactically complex or ambiguous sentences. Furthermore, anterior-interior temporal lobe is active for reading grammatical sentences than the unscrambled sentences. Mashal et al. (2009) reported that left anterior temporal lobe and left posterior middle temporal lobe is active for semantically plausible versus implausible sentences. Hubbard et al. indicates that activation occurs in the left temporal area for sentences with plausible semantics that were simple versus complex to predict. However, these activations at ATL is not specific to auditory input but activation can also be observed for written sentences. Furthermore, studies report when auditory sentences are accompanied by bodily gestures or the emotional expression of a speaker, activation is observed at left posterior middle temporal region. Dick and colleagues (2009) found that visual moments during speech increased activation in the left posterior temporal region irrespective of the integration between speech and visual moments. Many authors/critics are of the view that listeners try to find out the meaning not only in the spoken words but also in the visual moments that accompany the speech. Thus, left anterior temporal lobe and left posterior middle temporal regions are observed in multimodal sentence processing. Thus, for the syntactic processing of the language, different regions of the brain are activated. It is because higher levels of language require integration of several linguistic aspects such as phonemic, lexical-semantic, morphemic, prosodic or intonational. Visser et al (as cited in Price, 2010, p. 69) found that for both the semantic and syntactic processing of sentences activation is observed at anterior temporal region of the brain. Some of the researchers focuses on the syntactic processing of a specific cortical region, which remains unclear.

Likewise, evidences from the individuals with disrupted frontal basal ganglia due to stroke or disease leads to dysfunctioning of morphological regular inflections e.g., kick , kicked. While as the irregular morphological forms e.g., run, ran remains unaffected. It is because irregular morphemes are stored in the mental lexicon that have an easy lexical access. However, diseases that affect lexical system at the temporal lobe like semantic dementia affects the vice versa.

Activation at the left angular gyrus is less consistent for the sentence processing. However, it is reported that left angular gyrus accelerates sentence processing via top-down role of lexical-semantic process. Likewise, studies identified that activation at some regions of angular gyrus is observed for plausible vs implausible meaning of sentence, the role of angular gyrus can also be seen in speaking and writing processes, and there is a top-down role of angular gyrus in object naming tasks (as cited in Price, 2010, p. 70). In addition, bilateral anterior temporal region, posterior cingulate or precuneus, and posterior part of the left middle temporal gyrus is observed to play an active role in syntactic process with plausible versus implausible semantics.

When the sentence is complex to understand, ambiguous, grammatically incorrect, and implausible meaning, activation is observed in left pars opercularis. Several studies report that dorsal pars opercularis is active when meaning of sentences is difficult to comprehend, for grammatically correct sentences with implausible versus plausible meaning, for the sentences with semantic constraints, sentences with metaphoric expression versus literal meaning, for consistent versus inconsistent visual cues, for abstract versus concrete meanings. However, studies report that left dorsal pars opercularis has multimodal functionality i.e. the activation is not specific to semantic context only but to both linguistic and non-linguistic processes (sequencing of events). In addition, several researchers report the similar functionality of right inferior frontal region of the brain. Nevertheless, temporal and parietal regions shows consistent activation for the sentences with plausible meaning.

The region between Ppt and vSMG is associated with syntactic processes. Activation is observed for the sentences with syntactic constraints, syntactic complexity, semantic complexity, perceptually challenging context, and syntactically plausible but semantically implausible sentences. Some authors suggest that activation in pPT and vSMG is involved in phonological retrieval of words.

CONCLUSION

Due to the advancement of neurotechnologies, language is considered to stream widely throughout the brain between different regions. This paper has outlined the areas that are involved in the organization of linguistic behaviour. Therefore, different areas were shown to support the different aspects of language (phonology, semantics, and syntax) in integrational manner. Areas like aSTG, pSTG pSTS at temporal cortex are claimed to be a phonological hub. For instance, aSTG is bilaterally involved in phonological perception, pSTG is responsible for the phonological retrieval processes, pSTS is involved in representation of speech sounds that carries phonetic information. It is concluded that posterior lateral, inferior and middle temporal lobe is activated for the different semantic attributes and left posterior inferior temporal cortex for the word retrieval. Besides that anterior ventral inferior frontal region, is involved in the association of meaning of different words. Finally, Broca’s area is considered to be a core of syntactic production and comprehension. While as the role of ATL is found to be responsible for syntactically complex and ambiguous sentences. However, activation for the sentence processing was also found at left angular gyrus.

Further studies for language anatomy are still required to investigate the contribution of different regions and sub-regions by keeping certain points into consideration such as individual differences in neural networks, age, and multilingualism. Findings of several studies suggest that neural activation of language

© UIJIR | ISSN (O) – 2582-6417
FEBRUARY 2023 | Vol. 3 Issue 9
www.uijir.com

varies among individuals due to the different underlying structure of the brain. Hence, structural, and functional data must be taken into consideration in the future studies.

REFERENCES

1. Aboitiz, F., & Garcia .V. (1997). The evolutionary origin of the language areas in the human brain: A neuroanatomical perspective. *Brain Research Reviews,* 25, pp. 381–396.
2. Benjamin, C.F., Walshaw, P. D. , Hale, K., Gaillard, W. D., Baxter, L. C., Berl, M. M., Polczynska, M., … Bookheimer S. Y. (2017). Presurgical language fMRI: Mapping of six critical regions. ***H**uman **B**rain **M**apping 38, pp. 4239–4255*. DOI: 10.1002/hbm.23661
3. Binder, J.R., Desai, R. H., Graves, W.W., & Conant, L.L. (2009). Where is the semantic system? A critical review andmeta-analysis of 120 functional neuroimaging studies. *Cereb. Cortex. 19, pp. 2767–2796.*
4. Friederici, A. D. (2011). The brain basis of language processing: From structure to function. *Physiol Rev*, *91*, pp. 1357-1392. doi:10.1152/physrev.00006.2011
5. Hickok, G. (2009). The functional neuroanatomy of language. *Phys Life Rev, 6 (3),* pp.121-143. doi:10.1016/j.plrev.2009.06.001
6. Nasios G., Dardiotis, E., & Messinis, L. (2019). From broca and wernicke to the neuromodulation era: Insights of brain language networks for neurorehabilitation. *Behavioural Neurology, 2019*. https://doi.org/10.1155/2019/9894571
7. Poeppel, D., Emmorey, K., Hickok, G., & Pylkka¨nen, L. (2012). Towards a new neurobiology of language. *The Journal of Neuroscience, 32(41), pp. 14125–14131.* DOI:10.1523/JNEUROSCI.3244-12.2012
8. Price, C. J. (2000). The anatomy of language: contributions from functional Neuroimaging. *J. Anat.*, 197, pp. 335-359
9. Price, C. J. (2010). The anatomy of language: a review of 100 fMRI studies published in 2009. *Annals of the New York Academy of Sciences, 1191, pp. 62-88.* doi: 10.1111/j.1749-6632.2010.05444.x
10. Rauschecker, J.P. & Scott, S.K. (2009). Maps and streams in the auditory cortex: nonhuman primates illuminate human speech processing. *Nat. Neurosci. 12, pp. 718–724.* https://www.bing.com/images/blob?bcid=RNCd..mTJWkECVdBY44d-fRmhfhP.....6w