Ramya Ramnath Review Paper

Abstract

Language processing has conventionally been understood through studies on spoken language. This review focuses on extending this research to look at what studies on sign language reveals about the cortical organization of language. By comparing processing of spoken and sign language, we parse out regions in the language system that are responsible for language processing, regardless of modality. We compare the processing done by the superior temporal cortex, inferior frontal cortex, and parietal cortex, as these are the regions repeatedly shown to be responsible for language processing. These comparisons lead to an understanding of the dynamic organization of the language system in the brain such that structures are able to process different kinds of information depending on the type and reliability of input available.

Ramya Ramnath Review Paper

Signers and Speakers: A Dynamic Organization of Language in the Brain

The idea of cortical organization of language in the brain has changed since the first Wernicke-Geschwind model. Apart from understanding that language is organized into networks, not isolated regions, researchers have also come to realize that their definition of language needs to broaden. Along with exploring more complex stimuli like sentences and discourse, instead of phonemes, they have also started exploring language in different modalities, whether it is audio-visual speech or sign language.

In recent years, there has been a shift in the empirical ideologies of researchers regarding language such that they are starting to see sign language as an alternative language, rather than a handicap. This has been fueled by the understanding that sign language and spoken language employ similar structures of phonology, morphology, syntax, semantics, and pragmatics, thus providing several points of comparison between the two languages (Bavelier, Corina, &Neville, 1998).

As a result, research is being done on a more diverse population and using a broader stimuli base. This includes looking at deaf and hearing native signers and using visual stimuli such as sign language and TicTac, a collection of gestures used to communicate quickly between bookies. This kind of research has allowed us to explore questions such as how the modality of a language affects its cortical organization and whether linguistic and nonlinguistic information in the same modality is processed differently.

Comparing sign language and spoken language can lead to some fascinating findings that would have been difficult to arrive at otherwise. For example, Bavelier et al. (1998) explained that the difference in temporal contrasts for spoken and signed languages allow us to compare time constraints and its effect on language processing. In addition, sign language makes use of visuo-spatial information in a very different way than audio-visual speech, by using a classifier system, which will be explained later in this review (Bavelier, Corina & Neville, 1998). This allows us to look at the different ways language can be structured in the brain, depending on the modalities being used, or the different kinds of information being processed, depending on the prior knowledge of the language users (MacSweeney et al., 2008).

In this paper, we review research done on sign language to look at differences in the cortical organization of sign language, as compared to spoken language, and how this is affected by whether signers are deaf or hearing native signers. This research has led to interesting observations regarding the flexibility of certain language-related cortical systems in terms of the input they process. We will look at this flexibility by discussing the traditional regions associated with spoken language processing and analyzing their similarities and differences with sign language processing.

Temporal Lobe: The Comprehender

In the traditional Wernicke-Geschwind model, the posterior superior temporal regions are proposed to be responsible for comprehension. This has been replicated with sign language in multiple studies. Damage to posterior temporal structures in patient W. L. led to comprehension deficits such as single sign recognition and severe sentence comprehension deficits (Bavelier, Corina & Neville, 1998). In addition, neuroimaging studies comparing sign language between signers are non-signers have implicated various temporal regions in processing sign language. EEG studies have found activity in temporal regions for function signs in signers and function words in English speakers, implicating the temporal lobe in comprehension across modalities (Bavelier, Corina, & Neville, 1998). This finding has been replicated in fMRI studies and narrowed down to Wernicke's area or BA 22 (Bavelier, Corina, & Neville, 1998). These regions have found to be activated bilaterally, even though the language system is often conceptualized as left-lateralized (MacSweeney et al., 2006).

While most of these studies are conducted comparing processing of sign language between signers, and non-signers, there is some research comparing sign language to other kinds of gestures. This comparison allows us to look at processing of linguistic and non-linguistic information in the same population. fMRI studies that compare signers and non-signers processing sign language have found activation in left pSTG, pSTS and MTG for sign language as compared to TicTac or audio-visual speech (MacSweeney et al., 2008). A study comparing processing of American Sign Language (ASL) and nonsense signs that are phonetically legal is ASL found differentiated activation such that the secondary auditory cortex is more engaged in processing ASL signs, and hence linguistic information, than nonsense signs (MacSweeney et al., 2002). This activation of posterior temporal regions suggests that, due to lack of auditory experience, the STG becomes tuned to vision rather than audition (MacSweeney et al., 2002). Further research into more specific regions in the posterior STG has found significantly more activity in the planum temporale for signers than for non-signers. Therefore this region, often thought of as one of the secondary auditory cortices, has been implicated to be responsible for linguistic specificity rather than modality-specificity (MacSweeney et al., 2004). While most research has focused on posterior temporal regions, there is some evidence for the anterior temporal cortex, usually associated with semantics, being engaged for signed sentences and individual signs and therefore responsible for semantic associations in sign language (MacSweeney et al., 2006).

Frontal Lobe: The Producer

The inferior frontal region, specifically Broca's area (A 44, 45) in the inferior frontal gyrus, is considered to be responsible for language production. Lesion case studies have found that damage to Broca's area, or BA 44-45, result in effortful and dysfluent signing, despite comprehension abilities being intact, implicating the IFG in sign production (Bavelier, Corina, & Neville, 1998). Lesions in the prefrontal regions have also led to agrammatical signing, further emphasizing its role in production of coherent signing (MacSweeney et al., 2002). Corina and McBurney (2001) outline a cortical stimulation study performed on a patient undergoing left hemisphere surgery. The patient was asked to produce signs with his left hand while either Broca's area or the SMG was stimulated. Stimulation of Broca's area led to errors in motor execution of signs, showing that Broca's area is responsible for the motor output of signing. The role of this region in sign as well as speech production implies that it is largely modality-independent (Gordon, 2004).

Neuroimaging studies have further supported these findings. MacSweeney et al. (2008) outlined multiple fMRI studies comparing native and hearing signers that show that both covert and overt sign production rely on the left IFG, just as speech production does. The inferior frontal gyrus, is activated more for sign language perception than for TicTac perception (MacSweeney et al., 2008; MacSweeney et al., 2004). Sign language is considered to convey more linguistic information that TicTac, which is considered to be more pre-linguistic. The inferior frontal region shows increased activation for sign language as compared to TicTac. This implies that this region is involved in parsing linguistic and non-linguistic information in order for them to be processed differently. Bavelier et al. (1998) found that area BA 44-45 was recruited for ASL processing by native signers in the same way that it was recruited for English processing by native speakers, showing that activation in this region is independent of modality and language experience. Corina and McBurney (2002) found that Broca's area and the dorsolateral pre-central cortex showed differential activation for hearing signers and deaf signers. While this seems to contradict the experience-independent findings by Bavelier et al., it is possible that this region is employed by signers, regardless of whether they are deaf or hearing, but that deaf signers rely more on this region because they do not have the ability to rely on any other modality for input. In this way, this region might be weighted differently depending on the language experience of language users, but is used by all signers and speakers.

Parietal Lobe: The Map of Gestures in the Mind

Though the parietal lobe is often not associated with spoken language, this region is frequently identified as relevant to production and comprehension of sign language. As sign language is in the visual modality, it employs space in multiple ways to convey meaning. This use of space may be what causes parietal activation in sign language but not spoken language. Spatialized syntax and the use of classifiers are two specific examples of the use of space in sign language. Bavelier, Corina, and Neville (1998) defined spatialized syntax as the use of spatial mechanisms in order to serve grammatical functions. An example of spatialized syntax is the use of classifiers, morphologically complex gestures that convey visual characteristics of objects such as location, orientation, and movement. These are often used instead of prepositions. Most studies compare the use of classifiers to the use of preposition words in sign language to look at the effect of using topographical space to represent information.

Emmorey et al. (2001) compared left-hemisphere and right-hemisphere impaired signers for their comprehension of classifiers and found that production of classifiers engaged the supramarginal gyrus (SMG) bilaterally. They found that while the posterior SMG and superior parietal lobule are engaged in processing classifiers in signers, it is activated for visual motor planning and coordinate transformation processes in nonsigners. The SMG has also been implicated for describing spatial arrays (MacSweeney et al., 2008). Thus the SMG might be responsible for creating a mental representation of the spatial relationships between objects. This is then used to process spatialized syntax. MacSweeney et al. (2008) describe an fMRI study that showed that the inferior parietal lobule produced deficits in phonological processing whereas stimulating the superior parietal lobule produced deficits in proprioceptive monitoring, thereby providing a clearer distinction between the roles of different regions within the parietal lobe that are involved in sign language processing. This implicates the parietal lobules and the SMG in using internal models to understand spatial information, as expressed through classifiers.

As discussed before, a cortical stimulation study was conducted in which the SMG and Broca's area were stimulated during sign production during LH surgery. They found that stimulating the SMG produced deficits in correct selection of the linguistic components required for naming, thus causing formational and semantic errors (Corina & McBurney, 2001). This shows that the parietal lobe, especially the SMG, is responsible for more than just spatialized syntax and is also involved in the semantic association system of sign language.

Right Hemisphere Processing for Sign Language Specialties

Language systems have, for the most part, been conceptualized as left-lateralized networks. However, research into the cortical organization of sign language has shown that there is a larger participation of right hemisphere areas for sign language than for processing English (Bavelier, Corina, & Neville, 1998). This led to researchers considering the possibility that, much like the parietal lobe, the right hemisphere is responsible for aspects of sign language that do not directly relate to characteristics in spoken language.

Right hemisphere lesions have been associated with deficits in various aspects of spatial relationships, such as route finding, drawing, etc (Bavelier, Corina, & Neville, 1998). The same researchers have shown that processing American Sign Language occurs separate from processing arbitrary gestures for native signers. This shows that there is something about sign language gestures that distinguish them from other gestures. This is probably the use of classifiers to indicate characteristics in topographical space. This idea is resonated in research by Emmorey et al. (2001) that shows that right hemisphere damage leads to impaired ability to use topographic space for signing. Additionally, right hemisphere damage has also led to impaired visuo-spatial processing, regardless of language. These data show that the right hemisphere plays a significant role in processing and comprehending spatial relationships and the use of 3-dimensional space in order to communicate meaning. This is perhaps not the case in spoken language as, in spoken language, most spatial information is also communicated through auditory information from which the semantic properties are derived.

Another role that the right hemisphere is hypothesized to play is that of synthesizing information over a period of time in order to process meaning. Multiple studies have implicated the right hemisphere for processing whole ASL sentences (Corina & McBurney, 2001; Bavelier et al., 1998). In terms of spectro-temporal fields, the right hemisphere has been hypothesized to process input over longer units of time, thus being considered responsible for processing prosody, tone, puns, etc. This has been proposed for sign language too, whereby the right hemisphere is activated when making inferences about the emotional tone of language, to integrate meaning across ASL sentences, and to appreciate jokes and puns. This implies that the right hemisphere is able to integrate information over longer periods of time to analyze them for overarching information. The right hemisphere is responsible for spatial and prosodic information, thus playing the same role it plays in spoken language and additional and additional modality-specific roles.

Dynamic View of Language in the Brain

We have seen sign language and spoken language rely on a relatively similar network of brain regions. These consist of regions in the peri-sylvian cortex including inferior frontal gyrus (Broca's area), posterior superior temporal gyrus and sulcus (pSTG and pSTS), the anterior superior temporal lobe and the middle prefrontal cortex (Bavelier, Corina, & Neville, 1998). In addition, sign language relies on the supramarginal gyrus (SMG) and inferior and superior parietal lobules in order to process visuo-spatial information in relation to classifiers.

We have also seen that the traditional left-lateralization of language is lost in sign language as the right hemisphere is required to integrate visuo-spatial information and other overarching meaning. This shows that networks can expand and change depending on the information available and the reliability of this information. For instance, deaf signing participants relied more on the IFG while hearing signers relied more on the pSTG. The planum temporale and secondary auditory cortices also changed to process visual information when there was a lack of auditory information during the initial years of life. Again, this emphasizes the idea that the networks in the brain are dynamic and change depending on what information is available.

Such discoveries about alternate organizations of language in the brain emphasize that looking at different populations and different kinds of languages can be very useful in understanding how the language, and the more basic processes that language comprehension relies on, is organized in the brain.

Box 1. Dynamic nature of cortical regions for language processing

Deaf and hearing native signers rely more on the supramarginal gyrus than the hearing signers and non-signers. This is because they are accustomed to relying on the parietal lobe to process spatial information. Also, the increased activation in the superior temporal gyrus and sulcus for deaf native signers shows that this region is reconfigured to process visual input instead of auditory input. This is not the case in hearing native signers and non-signers because their STG is configured to process auditory information, which is absent in the British Sign Language (BSL) condition.

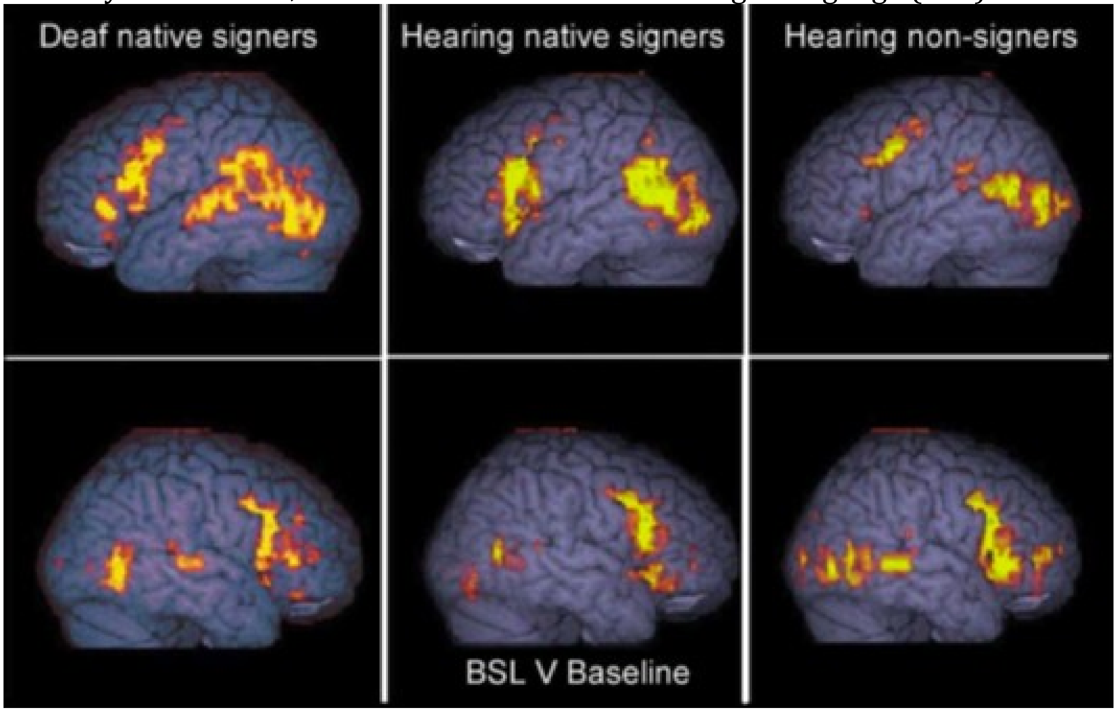

Figure 1. Relative activation for British Sign Language as compared to baseline condition of the signer at rest. (MacSweeney et al., 2006)

Outstanding Questions

- How does learning sign language as a second language affect the ability of the brain to reorganize networks such as restructuring the pSTG to process visual information? How does the age of acquisition affect this reorganizational process?
- For hearing signers, what effect does knowing sign language have on how they perceive gestures and other visual information in spoken language? Are they likely to weight gestures more than auditory input? Are they likely to be better at parsing cospeech gestures and other gestures better?
- As we have seen, lack of auditory information can have a strong effect on structural aspects of language in the brain. How does deficits in other modalities of input affect the cortical organization of language?
- Research has focused mainly on the cortex in terms of reorganization with reference to deaf populations. Does lack of auditory input since birth affect subcortical regions too? If so, in what way and to what extent are these subcortical regions responsive to such changes?

- References

Bavelier, D., Corina, D, Jezzard, P., Clark, V., Karni, A., Lalwani, A., Rauschecker, J. P., et al. (1998). Hemispheric specialization for English and ASL: left invariance-right variability. *NeuroReport*, *9*(7), 1537-1542.

Bavelier, D., Corina, DP, & Neville, H. (1998). Brain and language: a perspective from sign language. *Neuron*, *21*(2), 275-278.

Corina, D. P., & McBurney, S. L. (2001). The neural representation of language in users of American Sign Language. *Journal of Communication Disorders*, *34*(6), 455-471.

Corina, David, Chiu, Y.-S., Knapp, H., Greenwald, R., San Jose-Robertson, L., & Braun, Allen. (2007). Neural correlates of human action observation in hearing and deaf subjects. *Brain Research*, *1152*, 111-129.

Emmorey, K., Damasio, H., McCullough, S., Grabowski, T., Ponto, L. L. B., Hichwa, R. D., & Bellugi, U. (2002). Neural systems underlying spatial language in American Sign Language. *NeuroImage*, *17*(2), 812-824.

Gordon, N. (2004). The neurology of sign language. *Brain & Development*, *26*(3), 146-150.

MacSweeney, M., Campbell, R., Woll, B., Brammer, M., Giampietro, V., David, A. S., Calvert, G., et al. (2006). Lexical and sentential processing in British sign language. *Human Brain Mapping*, *27*(1), 63-76.

MacSweeney, M., Campbell, R., Woll, B., Giampietro, V., David, A. S., McGuire, P. K., Calvert, G. A., et al. (2004). Dissociating linguistic and nonlinguistic gestural communication in the brain. *NeuroImage*, *22*(4), 1605-1618.

MacSweeney, M., Capek, C., Campbell, R., & Woll, B. (2008). The signing brain: the neurobiology of sign language. *Trends in Cognitive Sciences*, *12*(11), 432-440.

MacSweeney, M., Woll, B., Campbell, R., McGuire, P. K., David, A. S., Williams, S. C. R., Suckling, J., et al. (2002). Neural systems underlying British Sign Language and audio-visual English processing in native users. *Brain: A journal of neurology*, *125*(Pt 7), 1583-1593.