Brain Activation during Signed and Spoken Language

Comprehension and Production – Study Proposal

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LING 4230 Language and the Brain

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December 11, 2023

1.0 Introduction

Both signed and spoken languages contain linguistic features and are natural ways in which people communicate with one another. The main difference between these modalities is that signed languages makes use of visible manual-gestural actions absent from auditory stimuli, whereas spoken language is the reverse of this as it is performed via oral articulators (Capek et al., 2008). While the principal phonological structures for signed languages include hand configuration, location, and movement, some signs utilize the addition of the mouth. All of which require sensory, motor, and cognitive coordination. Spoken language is often supplemented by co-speech gestures, however, such communicative channel is typically controlled or stripped away in experimental studies (Trettenbrein et al., 2021). Although in both signed and spoken languages, fluent language production appears effortless, coordination of large-scale and local cortical networks is required.

In the 1980s, researchers conducted case studies on deaf signers with left hemisphere damage and discovered sign language production and comprehension impairments. Specifically, they found left frontal damage correlated with sign production deficits and left temporal damage correlated with sign comprehension deficits (Emmorey, 2021). Early neuroimaging studies (Petitto et al., 2000) supported these findings, however, their validity has been a topic of concern in the field.

This study sets out to explore the differences that exist between signed and spoken languages. Such differences explored go beyond the verbal and visual modality contrast, but instead analyze the representation of these modalities inside the brain. Specifically, which brain regions are activated during signed and spoken language comprehension/processing and production? Moreover, are similarities found between each language modality?

2.0 Previous Literature

There are numerous ways researchers have investigated this very question. Participants involved in studies exploring this typically are either bimodal or monomodal. In studies involving bimodal participants, they communicate in both signed and spoken language, thus they can participate in all conditions. This is beneficial as each language modality can be compared directly in regard to the same brain/participant. Conversely, in studies with monomodal speakers, participants only know either sign or spoken language, thus two control groups would be needed. However, it is worth noting that different brain regions may function differently depending on numerous factors (Campbell et al., 2008).

2.1 Support for Commonalities Between Modalities

Several earlier imaging studies support the conclusion that sign language shares processing commonalities with spoken language processing such as perisylvian areas and frontotemporal networks (Campbell et al., 2008; Capek et al., 2008; Newman et al., 2015; Soderfeldt et al., 1994). One notable study includes Soderfeldt et al. (1994) which compared cerebral activation during comprehension of both language modalities. In the study, changes in the bimodal participant's regional cerebral blood flow (rCBF) were recorded to analyze fluctuations in neuronal activity. The study found that activation of posterior temporal regions for both spoken and signed language occurred as a result of comprehension of complex stimuli. It was concluded that "sign language activates the cortex in a way which is very similar to spoken language, when the listener watches the speaker" (Soderfeldt et al., 1994).

In the field of neuroscience, it is commonly known that the left-hemisphere of the brain is dominant for language processing. However, to what extent can such a statement be generalized?

In 2021, a study was completed by Trettenbrein et al. whose results showed support for the notion that sign language comprehension relies on the same left-hemispheric network used in spoken and written language comprehension. The study quantitatively reviewed 23 various functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) studies involving over 300 deaf signers through a meta-analytical approach. They used an activation likelihood estimation (ALE) approach to highlight brain regions that responded to sign language comprehension consistently across these studies. The results found sign language activates bilateral fronto-temporo-occipital regions with strong left-lateralization in the posterior Broca's region (inferior frontal gyrus) (Trettenbrein et al., 2021). This in fact mirrors functional asymmetries found in spoken and written language. Overall, this suggests that the left-hemisphere is not specialized to spoken and written languages, but instead more generally specialized to linguistic processing. The study found that within the sign language network, Broca's region acts as a hub responsible for assigning abstract linguistic information to gestures. Additionally, their findings provided evidence that sign language specific voxels within Broca's region are also important and involved in spoken and written language. Such results suggest that our brains have developed laterally where Broca's region contains a hub that computes linguistic information regardless of the presence/absence of speech. The fact that this hub in Broca's region can process linguistic information independent of speech supports the notion that signed and spoken languages are neurologically processed similarly.

2.2 Evidence of Activation Differences Between Modalities

Despite evidence from these studies, researchers have continued to poke at the question at hand, finding contradicting results. Aside from discovering processing variations between speakers of different spoken languages, researchers have also provided evidence for processing variation between modalities. Some documentation to back up this claim is provided by evidence from modality-dependent/modality-specific processing.

2.2.1 Evidence for Modality-Dependent/Modality-Specific Processing

Modality-dependent anatomical mechanisms involved in sign and spoken language are important differences worth mentioning. Research providing support for modality-dependent processing aims to grasp how sign and spoken languages are processed differently based on the modes of communication themselves. By considering confounds that invalidated previous processing comparison literature and investigating the conditions they emerge, modality-dependent processing differences have been uncovered. Modality-dependent differences encompass a variety of factors, including the timing of information processing, unique anatomical and electrophysiological mechanisms involved in language comprehension/processing and production, as well as special processing characteristics according to language modalities. While it is important to acknowledge the existence of cross-modality processing commonalities, it is equally important to consider the neglected differences.

Although the findings from Soderfeldt et al. (1994) (see Section 2.1) overall support the notion that sign and spoken language similarly activate the cortex, the differences found in the activation patterns appear to be a result of modality-specific processing requirements of the perceptual task as opposed to the linguistic aspect of it. Understandably, the auditory cortex in the superior temporal lobe was activated more by spoken language, whereas regions in the visual cortex such as the posterior and inferior temporal and occipital regions showed greater activation by signed language. All in all, the differences were found in specialized regions corresponding to each input modality. While the study does not ignore these differences, it appears that the similarities in activated brain regions are treated as greater importance.

Other studies involving language tasks with bimodal bilinguals native in both British Sign Language (BSL) and spoken English provide evidence for modality-specific processing. One such study found greater left-hemisphere activation for BSL comprehension in comparison to English comprehension (Caldwell, 2022). Such lateralization difference was not found in the non-signing and hearing conditions. Had the modalities processed comprehension the same, such an effect would not have been found. The effect is accredited with reflecting modality-specific processing. A detailed look investigating the activation of specific regions would provide more specific evidence for this.

A study by Capek et al. (2008) testing British Sign Language (BSL) and speechreading (i.e., spoken English) processing further supports this notion. While perisylvian regions were activated for BSL signs and speechreading English, disparities in activation were also found according to modality. Greater activation was found in the left mid-superior temporal cortex for speechreading than BSL. Conversely, BSL processing yielded larger activation at the temporo-parieto-occipital junction in both hemispheres. To examine this further, manual signs were paired with speech-like mouth actions (which convey information i.e. morphology). The manual-with-mouth actions showed greater superior temporal sulcus in both hemispheres and the left inferior frontal gyrus in comparison to signs made without the presence of these mouth actions. However, once these mouth actions were removed, the results changed. The manual-alone signs exhibited greater activation in the posterior and inferior temporal regions. This was specifically found in the right posterior temporo-occipital boundary which the researchers suggest that "when a signed language is being processed, this region is specialized for the perception of hand actions, quite specifically" (Capek et al., 2008). This provides support for modality-dependent processing as it proves that regions in the temporal cortex are sensitive/selective to the articulators for each language modality as well as the specific different articulators in the signed language. It brings awareness to the fact that the processing of linguistic information is dependent on the modality the input is coming from.

Further evidence for modality-dependent processing comes from analyzing brain activation during the rapid switch between different language modalities and comparing it to the switching between different spoken languages. In unimodal spoken language code-switching, the frontal lobe control regions are activated, however, this does not occur in bimodal code-switching. The exclusion of higher executive functions during bimodal code-switching "suggests that bimodal bilinguals solve this motor-articulatory competition in a unique way and with different mechanisms" (Caldwell, 2022). This acts as evidence that activation of brain regions is dependent on the modality at hand, thus impacting the processing that occurs.

2.3 Findings in Production-Specific Studies

Signed and spoken language production studies also find different anatomical areas activated. In 2001, Crone et al. conducted a cortical EEG study on a single participant who was proficient in both modalities. While spoken and signed word production activated various of the same cortical regions (especially those responsible for processing auditory and visual inputs), they too activated different regions of the sensorimotor cortex. Particularly, sign language production activated superior parietal regions. The study suggests that activation of the left superior parietal lobe is involved in the planning and execution of signs but not spoken language as such effect was not found in spoken word production. Instead, spoken word production found activation in temporal and occipital areas (Crone et al., 2001). Due to the small sample size of the study, the generalizability of it is questioned. However, apart from this study, various later studies verify these results. Results from MacSweeney et al. (2008) found despite regular spatial processing and sign production activating the left parietal lobe, the higher complexity of mapping of space to internal representations of signs during sign language production utilizes more activation in the right parietal lobe. Emmorey (2015) suggests that the additional activation of the right superior parietal lobe is unique to sign language and specifically associated with generating classifier information. The idea that the activation of a specific brain region being unique to sign language suggests support for modality-dependent processing/activation.

Additionally, recent research that has investigated sensorimotor activation linked to sign language and spoken language in bimodal bilinguals has uncovered distinct feedback mechanisms associated with each modality. Specifically, after sign language production, there is heightened activation in the postcentral gyri (lateral surface of parietal lobes) and superior parietal lobe, whereas in speech production, increased activity in the superior temporal sulcus and frontal areas was found. Moreover, there is greater activation in the bilateral occipital cortex regions following spoken language than sign language (Caldwell, 2022). Understandably, it can be generalized that signers' brains rely more heavily on somatosensory and spatial feedback in comparison to spoken language which depends more on visual and auditory feedback.

3.0 Methodology

3.1 Subjects

Fourteen subjects (mean age 27.3; range 20-38 years, seven females and seven males) participated in the study. Participants were divided in half and put into two separate experimental groups. The first group consisted of native speakers of English (spoken) and the second group were native American Sign Language Signers. All subjects were right-handed, had normal or corrected vision and reported no history of drug abuse. All participants were epileptic and diagnosed before the age of twelve. Informed consent was obtained from all participants prior to their participation. Ethics approval was issued by York University Ethics Committee Chair, Dr. Chandan Narayan.

3.2 Materials and Methods

Similar to Leonard et al.'s study (2020), each of the participants had a 256-channel grid (4mm inter-electrode spacing) surgically placed on their cortical surface. Participants' neural activity was recorded using electrocorticographic (ECoG) electrode arrays as they engaged in various language comprehension/processing and production exercises. ECoG was selected as it combines high temporal resolution with favourable spatial resolution – something that other technologies lack. Such technology provides the opportunity to characterize spatiotemporal dynamics of sensorimotor and linguistic manual movements. ECoG voltages were filtered, and high-gamma signals were extracted. High gamma responses were of interest as they correspond with multi-unit activity and possess strong connections with speech perception and production (Leonard et al., 2020). Data was inspected for noisy channels and other artifacts. Channels with the presence of these were excluded from the analysis.

Stimuli were either presented to participants on a computer screen placed directly in their field of view or delivered through headphones at 75 dB. Three cameras were used to record participants' responses throughout the duration of the procedure.

3.4 Stimuli

To test production, participants performed various activities including picture naming, reading, and word-repetition. Picture naming and reading stimuli were presented via computer screen. Picture naming stimuli included 50 black-and-white drawings of objects. The reading stimuli was a Grade 6 level paragraph, consisting of 153 words. Word repetition stimuli included an additional 50 separate unique stimuli. Words were presented auditorily through headphones. All stimuli varied in terms of number of syllables, word type, and difficulty in spelling-to-sound correspondence. Stimuli were presented in random order, one at a time.

For comprehension testing, participants were asked to watch a short video where their understanding of it was later evaluated in a written test. Participants completed all experimental tasks according to their language modality.

3.6 Expected Results

Based on previous literature, the following results are predicted and expected for the study:

Common perisylvian regions such as Broca's area were activated during sign and spoken language production and comprehension (Capek et al., 2008, Trettenbrein et al., 2021). Overall, sign language comprehension showed greater left-hemisphere activation than spoken language comprehension (Caldwell, 2022). Temporal regions were activated in both language modalities. Sign language comprehension/processing exhibited greater activation in posterior and inferior temporal regions than spoken language (Capek et al., 2008; Soderfeldt et al., 1994). Such findings support Capek et al. (2008) notion that states the activation of the posterior temporal regions is thought to be “intrinsic to SL [sign language] processing”. Sign language also found to have increased activation in temporo-occipital boundaries (Capek et al., 2008; Trettenbrein et al., 2021). Conversely, spoken language showed greater activation in the superior temporal lobe and frontal lobe areas than signed language (Caldwell, 2022; Capek et al., 2008; Soderfeldt et al., 1994).

During production testing, sign language exhibited activation in the parietal regions (Caldwell, 2022; Capek et al., 2008; Crone et al., 2001; MacSweeney et al., 2008). Similar to its results for comprehension/processing, spoken language showed increased activation in superior temporal and frontal areas (Caldwell, 2022). Additionally, increased activation was found in the occipital areas as well (Caldwell, 2022; Crone et al., 2001).

3.6 Discussion

From the research outlined, it is evident that to some degree, comprehension and production processes in both language modalities activate some of the same regions, however, the strength of activation (i.e. stronger activation of posterior and inferior temporal regions in sign language than spoken language) too varies between modalities. Additionally, evidence has also found support for the activation of different brain regions in each modality. One reason for this is due to issues raised from modality-dependent processing, which is essentially the notion that differences in activation between modalities can be explained by analogous mechanisms located in modality-specific cortical regions.

Many current theories of language processing are based solely on research from spoken languages and their corresponding writing formats. This narrow focus on one modality restricts the ability to fully understand the fundamental processes involved in languages as a whole. It also leaves the field susceptible to making assumptions about processes specific to spoken language and generalizing them to all language modalities. Doing so could cause issues in clinical practices as these theories are crucial for diagnosing and treating adverse cortical events, which for sign language communicators, would have inherent differences. To develop a more comprehensive understanding of language processing across all modalities, more research highlighting the precise and direct similarities and differences found between modalities is essential.

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