



PERSPECTIVITY-DEPENDENT AND - INDEPENDENT RELATIONSHIPS IN AMERICAN SIGN LANGUAGE AND SPOKEN ENGLISH AS POTENTIAL NEURAL CORRELATES FOR SPATIAL COMMUNICATION

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ABSTRACT:

Unlike English, which uses prepositional words to indicate spatial connections, American Sign Language (ASL) relies on the placement of the hands to do so. We used event-related fMRI to look at how well people understood ASL and acoustic English versions of phrases that were either perspective-dependent (PD; left/right) or perspective-independent (PI; in/on) (sentence-picture matching task). Consistent with a prior study involving written English, PD sentences activated the superior parietal lobule (SPL) on both sides of the brain, unlike non-spatial control phrases. According to the examination of ASL-English conjunctions, SPL activity is symmetrical for PD sentences but left lateralized for PI phrases. When comparing PD and PI expressions head-on, we found that SPL activation was higher for PD expressions of ASL but not PI expressions. SPL activation is higher for ASL PD expressions because of the mental shift needed to understand the signer's perspective on where things are in the signing environment. The data imply that understanding spatial language in ASL and English is supported by a combination of overlapping and unique brain areas.

Keywords: English, fMRI, Sign language, Deaf, Spatial language.



1. INTRODUCTION

If you want to understand someone who is using a spatial language, you need a way for your brain's spatial processing abilities to interact with your language apparatus (Landau & Jackendoff, 1993). Non-linguistic, category spatial associations appear to be processed in the left parietal cortex, where the precise metric specification of the spatial arrangement is unimportant and clusters of places (such as variants of the above) are viewed as equal (Amor apanth et al., 2010). In addition, the supramarginal gyrus of the left parietal brain has been implicated in both production and comprehension of spatial prepositions, suggesting that the left parietal cortex serves as an interface between spatial cognition and language in both cases (e.g., Noordzij et al., 2008). When it comes to encoding geographic connections, sign languages often use verbal classifier structures rather than lexical prepositions (Emmorey, 2003). The spatial connection is ichnographically expressed by the position of the hands in respect to one another, with the non-dominant hand representing the ground object and the dominant hand representing the figure object (Emmorey, 1996). Instead, the signer must infer the spatial connection between objects from the orientation of the two hands in signing space. Such frameworks for a less binary, more continuous depiction of a figure object's placement, such as the use of varying heights for above and below (Emmorey, 2003). Deaf signers with visual-spatial processing deficiency may have trouble understanding and creating spatial classifier structures since doing so may rely on skills unrelated to language (Atkinson et al., 2002). The lesion results also show that both hemispheres are involved in the signing process, since both people with aphasia (injury to the left hemisphere) and people with unilateral damage to the right hemisphere make mistakes while signing classifier constructions (Hickok et al., 2009). In contrast, neuroimaging studies of spoken

languages and lesion data imply that the left parietal cortex is heavily involved in the formation of spatial prepositions (Damasio et al., 2001). Errors in naming spatial connections are made by speakers with injury to the left parietal lobe, particularly the white matter just beneath the inferior parietal operculum (Tranel & Kemmerer, 2004). Thus, the existing evidence suggests that the left parietal lobe, and maybe the right superior parietal lobe as well, are involved in the production of locative claims in spoken language, but the left superior parietal cortex is not.

However, it is not known if bilateral SPL is also involved during the understanding of spatial classifier constructs. Deaf individuals who use BSL were studied by MacSweeney et al. (2002) using fMRI; the aim was to identify the odd semantically aberrant statement. Different from non-topographic sentences, topographic sentences make use of the signing space and/or the signer's body to convey spatial information. By comparing the two, we found that the topographic words activated the left parietal brain more than the right. There was a broad variety of structures in the topographic statements, and they weren't all concerned with location. Because only a small number of topographic words involved mapping the placement of the hands in signing space to the location of figure and ground referents, it is plausible that activity in right parietal cortex was not seen for these sentences. Furthermore, Atkinson et al. (2005) discovered that compared to healthy older control signers, BSL signers with unilateral right hemisphere injury had trouble understanding sentences that represented spatial connections using classifier constructs. Signers with injury to their left hemisphere also showed difficulties, indicating that understanding locative classifier constructs requires activity in both brain halves.

When ASL signers understood sentences that expressed place and motion information, Newman et al. (2015) found no



activation in superior parietal cortex, in contrast to a "backward/layered" controlled group in which the sentence videos were got to play backward to three different videos superimposed. The control task involved determining whether or not three hands in the film all had the same handshape at the same time, whereas the experimental task involved determining whether or not a statement matched a previous video. To the best of our knowledge, no neuroimaging investigation has yet examined which brain areas aid in understanding locative classifier formulations that explicitly represent spatial connections.

On the other hand, studies have been done to look at the neurological correlates for understanding spatial prepositions in spoken languages. Noordzij et al. (2008) utilized fMRI to investigate the differences in comprehension of spatial emotions (circular left, triangle) and non-spatial statements when participants were asked to determine if a given written sentence matched another writing or an image (circle and triangle). The left parietal cortex, and in particular the left right superior gyrus, showed higher activity while processing spatial information as opposed to non-spatial information. Conder et al. (2017) argued that the lack of right hemisphere activation occurred despite the fact that the contrasts involved visual and decision-making brain activity. Conder et al. (2017) suggest that the observed analyses frequently include synaptic activations involved with task (e.g., handling a picture) and including activations connected with analyzing the locational language under investigation, which may account some of the disparities in the position of the correct parietal cortex in high ability parts of speech. To circumvent this problem, Conder et al. (2017) used an incident design in which participants were asked to decide whether or not auditorily viewed spatial phrases (such as

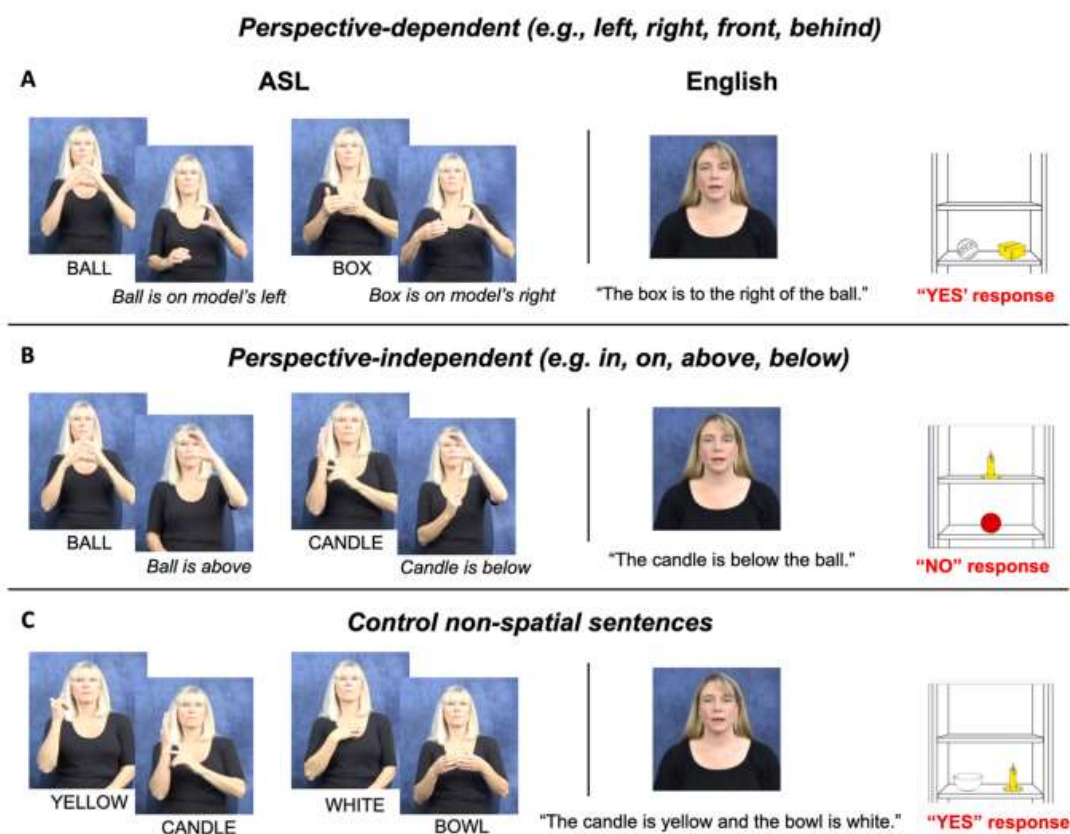
"The triangle is just below square") compared a picture that every now and then followed the sentence, and trials in which no picture matched this same sentence were omitted from analysis. It has been found that the right superior lobule and anterior cingulate cortex on both side of the brain become more active while processing spatial assertions, as compared to non-spatial terms expressing size or colour.

The current research used the same method as Conder et al. (2017), which compared how well deaf signers and hearing listeners understood spatial and non-spatial words delivered in ASL and audio-visual English, respectively. Though studies of the neurological underpinnings for spatial language have often lumped together all three forms of spatial relationships, understanding each may need a unique set of mental operations. Perspective-independent expressions can be understood regardless of the speaker's or writer's point of view. Whether the listener or the speaker/signer is standing, sitting, or lying down, the figure/ground connection will always be the same. In contrast, the addressee needs to take into account the viewpoint of the speaker or signer in order to understand perspective-dependent spatial expressions (left of) (Levinson, 2003).

Janzen et al. (2012) used fMRI to compare the neural activation during the understanding of relative and intrinsic PD phrases to that during the comprehension of non-spatial control sentences. The writers made use of the fact that statements like "The ball is behind the guy" can be construed in two ways, depending on whether they are read as being about the spectator or the man. In this research, we focus on PD phrases that are completely free of ambiguity but can be understood in just one of two relative contexts.

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Fig. 1. examine unambiguous PD sentences [1]

Expressions of personal development (PD) in ASL follow the conventions of other sign languages by being framed from the viewpoint of the signer (Pyers et al., 2015). To sign "The penalty area is to the left of the soccer ball," for instance (as seen in Fig. 1A), the signer would position a classifier handshape for the box to her left and a classifier handshape for the ball to her right. While the 'box' classifier is on the right when viewed by someone facing the signer, the 'ball' classifier is on the left. To understand the English counterpart of an audio-visual sentence-image matching test, no such mental shift is necessary (Fig. 1A). These results imply that understanding PD expressions in ASL may need more brainpower than understanding PI expressions in ASL, which do not necessitate this kind of cognitive shift (see Fig. 1B). We expect that ASL signers' parietal cortex will be more active when they understand PD phrases than when they understand PI sentences.

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Finally, this study used movies with either ASL spatial expressions or their English versions to contrast the performance of deaf petitioners and normal speakers on an ad hoc phrase matching test. The spatial phrases conveyed either PI or PD information, whereas the control words referred to the hues of the foreground and background objects. Our goals were (a) to find out if ASL signers and English speakers use the same brain areas to understand PD and PI spatial expressions, and (b) to find out if the brain areas used to understand PD and PI spatial expressions are different.

2. METHODS

2.1. Participants

Eighteen hearing English speakers (mean age 26.3; standard deviation = 6.7) and fourteen deaf signers (mean age 29.6; standard deviation 4.35 years) took part in the study. Sign language (ASL) was first introduced to all deaf signers before the age of 6, and all of them were severely deaf. All of the deaf participants said they often used ASL with hearing people, whether it was at home,



school, or job. All participants were hearing English-only native speakers with little to no prior exposure to American Sign Language. Participants were all right-handed and either had 20/20 vision or needed corrective lenses. There were no cases of neurological or behavioural abnormalities recorded among the subjects, either present or in the past. Welch's two-sample t-test found no significant difference in mean age between the groups ($t=1.54$, $df=22.8$, $p=.138$).

2.2. Stimuli

We videotaped 48 ASL statements from our model, a deaf female native signer, in which she described the relationship between two objects in space (PD and PI conditions). Each viewpoint had 24 words, with each spatial sentence containing nouns for two of a set of five objects (vase, bowl, ball, candle, and box) and expressing one spatial connection from a set of eight planning and design process (PD: left, right, behind, in front of; PI: above, below, in, on). Fig. 1 depicts a few sample phrases. When describing an object's position in American Sign Language, the ground object is often mentioned first.

We videotaped 24 ASL phrases in the non-spatial language condition, in which the signing model represented two things in sequence in a neutral environment. In this case, there was no indication of where things were located in the phrases. We also crafted grammatical counterparts in standard English, with precise descriptions of spatial and nonspatial circumstances using the same color coding for objects. We videotaped an American woman who spoke English as her first language uttering the lines. The Appendix includes a list of the English sentences with their corresponding American Sign Language (ASL) translations. Videos of both signed and spoken words were captured in 480p (3:2) format and edited in Apple Final Cut Pro. There were no longer than 4-second video samples of signed ASL or spoken English.

2.3 fMRI design and procedure

For optimal estimating efficiency, the software generated two runs of

counterbalanced and jittered trials lasting 5 minutes and 56 seconds each (Dale, 1999). With each trial, participants saw a 4-second video clip followed by a fixation time that ranged from 4-to-10 seconds, as calculated by the Opstseq2 software. Participants were asked to determine if the spatial connection or color descriptors in the previous statement were reflected in the line drawings. Participants were prompted to provide as precise and timely of responses as they could manage. Accuracy and RTs of participants were recorded. Hearing individuals were given spoken instructions, whereas those who use ASL received written ones. Before entering the scanner for the actual experiment, participants completed eight practice trials using novel stimuli.

2.4. MR image acquisition

The MRI scans were conducted at the Center for Functional Magnetic resonance imaging at the University of California, San Diego, using a 3-Tesla GE MR750 scanner outfitted with an 8-channel head coil. During the middle of the session, high-resolution structural images of each participant's brain were acquired using a T1-weighted Fast Spoiled Gradient-Recalled Echo sequence (FOV 256 mm, 256 x 256 matrix, 1 mm 1 mm in-plane resolution, 176 1 mm thick sagittal slices, flip angle = 8, inversion time = 600 ms) for anatomical reference and spatial normalization. All structural and functional pictures were visually examined for signs of major brain abnormalities or head movements (e.g., blurring, ghosting, or stripping). For ASL, we compiled two functional scans (183 EPI volumes), and for English, we compiled two functional scans (167 EPI volumes). Magnetization may reach steady state before stimulus presentation because the first five "dummy" volumes of each functional scan were discarded during pre-processing.

2.5. fMRI pre-processing and data analysis

The AFNI program was used to prepare all of the MRI data for analysis. After collecting all of the EPI data for a given area, a field map was created to account for any geometric distortion that may have occurred



during scanning. In addition, we performed spatial smoothing (6 mm full-width half-maximum Gaussian kernel), head motion correction (3dvolreg), and slice timing correction (3dTshift) on all EPI data sets. The structural MRI images of all individuals were registered to MNI-152 T1 standard space, and the corresponding EPI datasets were aligned to those images. Group-level multiple comparison correction was performed using 3dClustSIM after we estimated the smoothness of participant datasets using AFNI 3dFWHx (with the -ACF option). First, we used AFNI's 3dLME to conduct repeated-measures analyses on a linguistically discrete basis for the second-level analyses.

We analysed the PD lines minus the controlled sentences and the PI words minus the control words both in ASL and English using standard linear analysis through AFNI's 3dLME. When analysing the direct language contrasts, it is necessary to keep in mind that the shock duration for the ASL and English utterances were 4 s and 3 s, respectively. There should be little to no discernible variation in response time between languages if the adjustments (e.g., PD minus control texts from each dialect) are sufficient to compensate for the shift in stimulus duration. However, it cannot be ruled out that variations in stimulus duration played a role in the observed linguistic variances.

3. RESULTS

3.1. Behavioural results

Due to technological difficulties, we were unable to use the behavioral data from one deaf and two hearing subjects. A linear mixed-effects model (with individuals as random intercepts) showed that there was no difference in RT across groups ($F(1,23) = 2.2$, $p = .15$), and that there was no interaction between groups and sentence conditions ($F(2,46) = 0.86$, $p = .43$). A major impact of sentence condition was found, however, with $F(2,46) = 11.7$, $p = .0001$. When comparing RTs for PD and control phrases, $Z = 1.29$, $p = .39$ indicates no significant difference. $F(1,72) = 0.0006$, $p = .94$, and $F(2,72) = 1.56$, $p = .22$ show that ASL signers and English speakers did not significantly differ in their answer accuracy. However, the condition-by-condition variation in accuracy was statistically significant ($F(2,72) = 5.58$, $p = .006$). Based on post hoc analyses, it was determined that the accuracy of replies to non-spatial control sentences was lower than that to PD phrases ($Z = 2.43$, $p = .04$) and PI sentences ($Z = 3.19$, $p = .004$). $Z = 0.76$, $p = .73$ indicates that there is no statistically significant difference in the accuracy of responses between PD and PI phrases.

3.2. fMRI results

We compared PD and PI speakers' brain activity to that of a non-spatial control group using whole-brain analysis at a second level. To keep things simple, we only show brain activity up to 25 mm just below cortical plate in the figures.



Perspective-dependent vs. Non-spatial control sentences

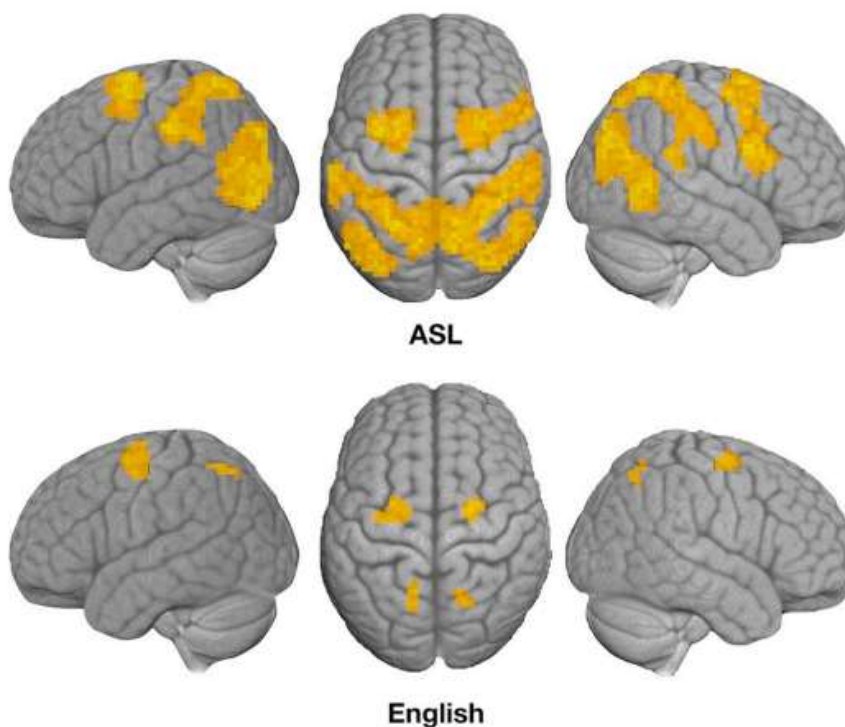


Fig. 2. Statistical maps, adjusted for multiple comparisons using FWE, highlighting significant areas of brain activity up to 25 mm under the cortical surface were generated for each language [1]

Perspective-independent vs. Non-spatial control sentences

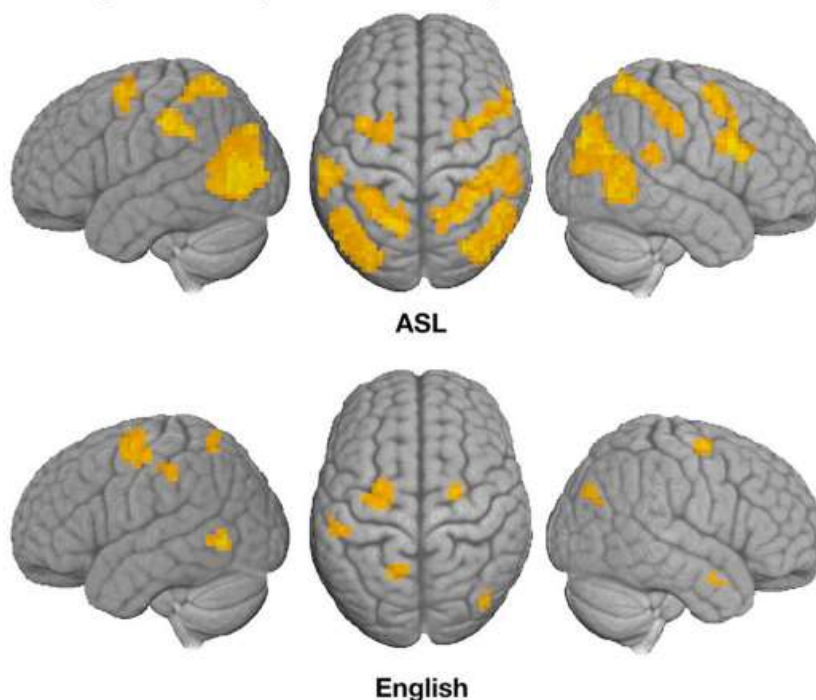


Fig. 3. Statistical maps, adjusted for multiple comparisons using FWE, revealing substantial areas of brain activity up to 25 mm below the cortical surface, for each of the six languages studied [1]

3.2.1. Perspective-dependent (PD) spatial connection activation regions

Brain areas that were substantially more active for PD spatial language compared

to the non-spatial language control are shown in Fig. 2. Brain scans show that the ASL group has increased activity in the left inferior frontal gyrus, the right parietal gyrus, and the middle frontal gyrus, as well as in the parietal and parietal cortices on both sides of their heads. Activation in parts of the brain not shown in Fig.

When interpreting the non-spatial texts, ASL users displayed high activity only in the right temporal lobe and the left insula. The superior temporal cortex and the left middle superior frontal cortex showed greater activity in native English speakers as they processed non-spatial sentences.

3.2.2. Perspective-independent (PI) connection activation regions

Brain activation patterns for PI spatial language are shown in Fig. 3, with comparisons to a control condition in which no spatial language was used. Images of the brains of ASL native speakers show activity in several regions: the left and right posterior

anterior gyri, the right middle frontal hippocampus, the left middle occipital gyrus, the right gyrus gyrus, the left and right superior frontal gyri. English speakers' brains show evidence of bilateral activity in the forebrain frontal gyrus, left posterior parietal hemispheres, left superior parietal lobes, left posterior medial temporal gyrus, right anterior middle temporal gyrus, and right inferior cortical lobule (Fig. 3, bottom). Clusters of neurons in the left medial temporal pole and cerebellar lobe VII are not depicted in Fig. 3.

3.2.3. Comparison of a PD sentence with a PI sentence

The ASL PD and PI contrasts map shows increased activity in the lateral superior prefrontal gyrus for PI sentences and increased activity in the precuneus / high parietal infundibulum for PD phrases ($p < .05$, corrected) (Fig. 4). There was no noticeable difference in brain activity across spatial language types and native English speakers.

Perspective-dependent vs. Perspective-independent sentences

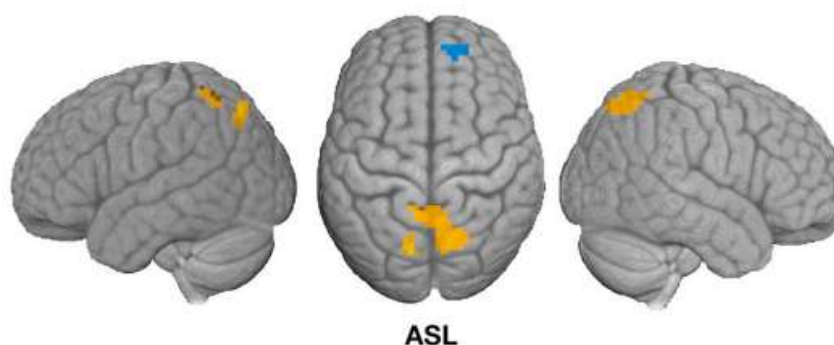


Fig. 4. Statistics adjusted for multiple comparisons were projected onto a template brain, revealing considerable activity up to 25 mm under the surface when comparing perspective-dependent and perspective-independent spatial phrases in American Sign Language.[1]

3.2.4. ASL and English Sentence Conjunction Maps

The common brain areas for all of these spatial meaning across language were identified using connection studies, where the minimum stat was compared to the connection null technique applied to the difference maps between the perspective-dependent and perspective-independent conditions (ASL and spoken English). It was shown that processing PD sentences activates the same regions of the brain regardless of

language: the contralateral inferior frontal gyrus and the parietal lobes (Fig. 5, top).

3.2.5. Similarities and differences between American Sign Language and English

Since there was such a large gap between the length of the spoken and signed sentences, we recommend exercising caution when interpreting the results of the whole-brain dialect juxtaposition (American Sign Language vs. English) for the PD minus control sentences and the PI minus control sentences (Fig. 6). The brain regions of ASL signers that



were shown to be more active than those of English PD were the fusiform gyrus gyrus, anterior cingulate nucleus, middle temporal lobe, and upper parietal lobe. Greater activity was observed in the left forebrain, the middle

temporal gyrus, and the brain among ASL users. However, there was no discernible pattern in the percentage of English residents who utilized PD sentences.

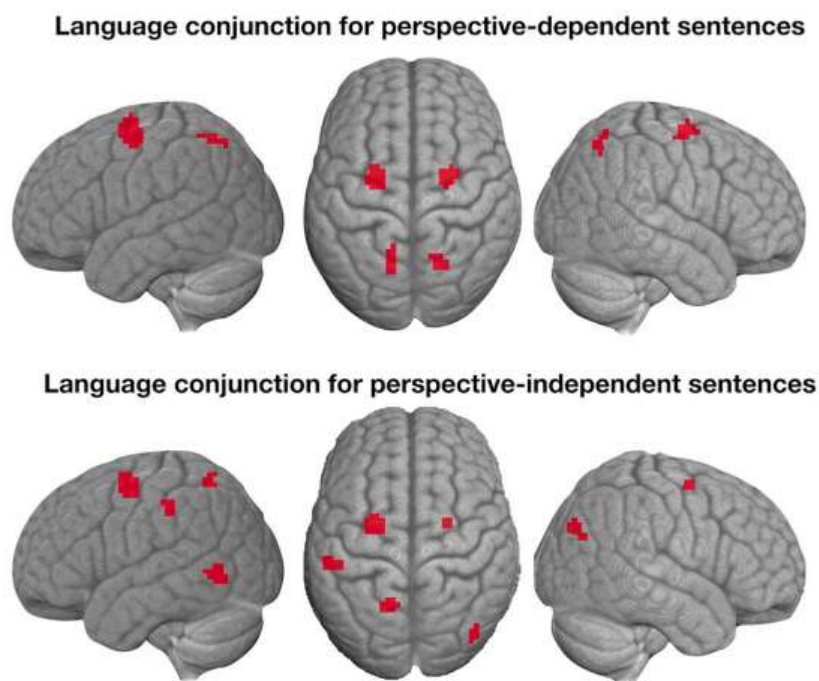


Fig. 5. Conjunction maps projected onto a template brain[1]

More brain activity was found in the areas of the brain associated with processing PI sentences in ASL compared to English. These regions comprised the medial temporal gyrus, the medial temporal gyrus, the right occipital gyrus, and the left lower parietal lobe and occipital gyrus. The bilateral insula and left parietal lobe gyrus of native English speakers were more engaged than those of ASL signers when processing PI sentences.

4. DISCUSSION

To our knowledge, this study is the first to investigate which regions of the brain are necessary for comprehending signed English phrases that refer to spatial relationships. Findings suggest that the parietal lobe lobule has a role in both the production and comprehension of locative classifier components in American Sign Language (Emmorey et al., 2002). Because this region speaking abilities between sensory processing and physical language, we argue that it is fully involved in both comprehension and production. Therefore, SPL may be involved in the calculation that transfers

knowledge of an object's spatial arrangement from a linguistic to a non-linguistic mental representation. Skills that are likely to be included in such a computation include paying attention to planning and design process, updating and encoding separate elements in space, and using supralocal interpretations of spatial information.

In particular, the researchers hypothesized that activating the anterior frontoparietal areas of the spatial processing network was necessary for paying focus to internal representations of topographical spatial maps. Spatial expressions in both ASL and English need a similar abstract model of the physical arrangement of person and ground elements, despite their structural and modality differences. The conjunction analysis also revealed that, contrary to what we expected, SPL activation is left-lateralized for PI phrases. These side-by-side analyses reveal that the dominant superior parietal lobe (SPL) is activated while processing PD phrases (Fig. 2, bottom), whereas the left SPL is used when analysing PI words (Fig. 3, bottom). As a



whole, our findings suggest that right SPL may play a role in understanding the relative viewpoint of spatial language.

PI sentences highlight the topological link (in, on, above, below) of figure and ground components in a spatial configuration without taking into account the reader's perspective. The dorsal fronto-parietal network is more active in ASL users than it is in English speakers during PD text summarization (compared to nonspatial control sentences). The results confirm our prediction that it takes more cognitive effort to understand PD sentences in ASL, as the listener must mentally map out the signer's perspective on the areas depicted in the signature space (see Fig. 1A). Since there is no contradiction between the presenter's and the listener's views for perspective-dependent words, no such mental shift is required to comprehend English sentences in just this paradigm of matching ideas to images (such as "right" and "left"). Keeping track of the non-spatial control words is unnecessary since they have no impact on motions toward a place in neutral space (or on the body). Topographic lines in BSL were found to activate the bilateral hind MTG ($L > R$) more than non-topographic phrases, as found by MacSweeney et al. To a similar extent, we discovered that the position of the signer's palms in reading space was significant for topographic words in BSL but not for other types of phrases. Based on our findings, it is clear that both authors and speakers utilize bilateral SPL when comprehending spatial words that depend on a person's point of view. We propose that the higher level of mental effort needed to interpret these sentence forms in American Sign Language is to blame for this linguistic difference (Brozdowski et al., 2019).

REFERENCES

- [1]. Emmorey, K., Brozdowski, C., & McCullough, S. (2021). The neural correlates for spatial language: Perspective-dependent and-independent relationships in American Sign Language and spoken English. *Brain and Language*, 223, 105044. <https://doi.org/10.1016/j.bandl.2021.105044>
- [2]. Amorapanth, P., Kranjec, A., Bromberger, B., Lehet, M., Widick, P., Woods, A. J., Kimberg, D. Y., & Chatterjee, A. (2012). Language, perception, and the schematic representation of spatial relations. *Brain and Language*, 120(3), 226–236. <https://doi.org/10.1016/j.bandl.2011.09.007>
- [3]. Amorapanth, P., Widick, P., & Chatterjee, A. (2010). The neural basis for spatial relations. *Journal of Cognitive Neuroscience*, 22(8), 1739–1753. <https://doi.org/10.1162/jocn.2009.21322>
- [4]. Atkinson, J. R., Woll, B., & Gathercole, S. (2002). The impact of developmental visuospatial learning difficulties on British Sign Language. *Neurocase*, 8(6), 424–441. <https://doi.org/10.1076/neur.8.5.424.16176>
- [5]. Atkinson, J., Marshall, J., Woll, B., & Thacker, A. (2005). Testing comprehension abilities in users of British Sign Language following CVA. *Brain and Language*, 94(2), 233–248. <https://doi.org/10.1016/j.bandl.2004.12.008>
- [6]. Binder, J. R., Desai, R. H., Graves, W. W., & Conant, L. L. (2009). Where is the semantic system? A critical review and meta-analysis of 120 functional neuroimaging studies. *Cerebral Cortex*, 19(12), 2767–2796. <https://doi.org/10.1093/cercor/bhp055>
- [7]. Brozdowski, C., Secora, K., & Emmorey, K. (2019). Assessing the comprehension of spatial perspectives in ASL classifier constructions. *The Journal of Deaf Studies and Deaf Education*, 24(3), 214–222. <https://doi.org/10.1093/deafed/enz005>
- [8]. Committeri, G., Galati, G., Paradis, A.-L., Pizzamiglio, L., Berthoz, A., & LeBihan, D. (2004). Reference frames for spatial cognition: Different brain areas are involved in viewer-, object-, and



- landmark-centered judgments about object location. *Journal of Cognitive Neuroscience*, 16(9), 1517–1535. <https://doi.org/10.1162/0898929042568550>
- [9]. Cona, G., & Scarpazza, C. (2019). Where is the “where” in the brain? A meta-analysis of neuroimaging studies on spatial cognition. *Human Brain Mapping*, 40(6), 1867–1886. <https://doi.org/10.1002/hbm.v40.6.10.1002/hbm.24496>
- [10]. Conder, J., Fridriksson, J., Baylis, G. C., Smith, C. M., Boiteau, T. W., & Almor, A. (2017). Bilateral parietal contributions to spatial language. *Brain and Language*, 164, 16–24. <https://doi.org/10.1016/j.bandl.2016.09.007>
- [11]. Corbetta, M., Shulman, G. L., Miezin, F. M., & Petersen, S. E. (1995). Superior Parietal Cortex Activation During Spatial Attention Shifts and Visual Feature Conjunction. *Science*, 270(5237), 802–805. <https://doi.org/10.1126/science.270.5237.802>
- [12]. Cox, R. W. (1996). AFNI: Software for analysis and visualization of functional magnetic resonance neuroimages. *Computers and Biomedical Research*, 29(3), 162–173.
- [13]. Creem, S. H., & Proffitt, D. R. (2001). Defining the cortical visual systems: “What”, “Where”, and “How”. *Acta Psychologica*, 107(1), 43–68. [https://doi.org/10.1016/S0001-6918\(01\)00021-X](https://doi.org/10.1016/S0001-6918(01)00021-X)
- [14]. Culham, J. C., & Valyear, K. F. (2006). Human parietal cortex in action. *Current Opinion in Neurobiology*, 16(2), 205–212. <https://doi.org/10.1016/j.conb.2006.03.005>
- [15]. Dale, A. M. (1999). Optimal experimental design for event-related fMRI. *Human Brain Mapping*, 8(2–3), 109–114. [https://doi.org/10.1002/\(SICI\)1097-0193\(1999\)8:2/3<109::AID-HBM7>3.0.CO;2-W](https://doi.org/10.1002/(SICI)1097-0193(1999)8:2/3<109::AID-HBM7>3.0.CO;2-W)
- [16]. Damasio, H., Grabowski, T. J., Tranel, D., Ponto, L. L. B., Hichwa, R. D., & Damasio, A. R. (2001). Neural Correlates of Naming Actions and of Naming Spatial Relations. *NeuroImage*, 13(6), 1053–1064. <https://doi.org/10.1006/nimg.2001.0775>
- [17]. Emmorey, K. (1996). The confluence of space and language in signed languages. In P. Bloom, M. Peterson, L. Nadel, & M. Garrett (Eds.), *Language and Space* (pp. 171–209). Cambridge, MA: MIT Press.
- [18]. Emmorey, K. (2003). *Perspectives on Classifier Constructions in Sign Languages*. Psychology Press.
- [19]. Emmorey, K., Corina, D., & Bellugi, U. (1995). Differential processing of topographic and referential functions of space. In K. Emmorey, & J. Reilly (Eds.), *Language, Gesture, and Space* (pp. 43–62). Hillsdale, NJ: Lawrence Erlbaum Associates.
- [20]. 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. <https://doi.org/10.1006/nimg.2002.1187>
- [21]. Emmorey, K., Grabowski, T., McCullough, S., Ponto, L. L. B., Hichwa, R. D., & Damasio, H. (2005). The neural correlates of spatial language in English and American Sign Language: A PET study with hearing bilinguals. *NeuroImage*, 24(3), 832–840. <https://doi.org/10.1016/j.neuroimage.2004.10.008>
- [22]. Emmorey, K., & Herzig, M. (2003). Categorical versus gradient properties of classifier constructions in ASL. In K. Emmorey (Ed.), *Perspectives on classifier constructions in signed languages* (pp. 222–246). Mahwah, NJ: Lawrence Erlbaum Associates.



- [23]. Emmorey, K., McCullough, S., Mehta, S., Ponto, L. L. B., & Grabowski, T. J. (2013). The biology of linguistic expression impacts neural correlates for spatial language. *Journal of Cognitive Neuroscience*, 25(4), 517–533. https://doi.org/10.1162/jocn_a_00339
- [24]. Glover, S. (2004). Separate visual representations in the planning and control of action. *Behavioral and Brain Sciences*, 27(01). <https://doi.org/10.1017/S0140525X04000020>
- [25]. Hickok, G., Pickell, H., Klima, E., & Bellugi, U. (2009). Neural dissociation in the production of lexical versus classifier signs in ASL: Distinct patterns of hemispheric asymmetry. *Neuropsychologia*, 47(2), 382–387. <https://doi.org/10.1016/j.neuropsychologia.2008.09.009>
- [26]. Jager, G., & Postma, A. (2003). On the hemispheric specialization for categorical and coordinate spatial relations: A review of the current evidence. *Neuropsychologia*, 41 (4), 504–515. [https://doi.org/10.1016/S0028-3932\(02\)00086-6](https://doi.org/10.1016/S0028-3932(02)00086-6)
- [27]. Janzen, G., Haun, D. B. M., & Levinson, S. C. (2012). Tracking Down Abstract Linguistic Meaning: Neural Correlates of Spatial Frame of Reference Ambiguities in Language. e30657 *PLOS ONE*, 7(2). <https://doi.org/10.1371/journal.pone.0030657>.
- [28]. Kemmerer, D. (2006). The semantics of space: Integrating linguistic typology and cognitive neuroscience. *Neuropsychologia*, 44(9), 1607–1621. <https://doi.org/10.1016/j.neuropsychologia.2006.01.025>
- [29]. Kosslyn, S. M. (1987). Seeing and imagining in the cerebral hemispheres: A computational approach. *Psychological Review*, 94(2), 148–175. <https://doi.org/10.1037/0033-295X.94.2.148>
- [30]. Kravitz, D. J., Saleem, K. S., Baker, C. I., & Mishkin, M. (2011). A new neural framework for visuospatial processing. *Nature Reviews Neuroscience*, 12(4), 217–230. <https://doi.org/10.1038/nrn3008>
- [31]. Laeng, B. (1994). Lateralization of Categorical and Coordinate Spatial Functions: A Study of Unilateral Stroke Patients. *Journal of Cognitive Neuroscience*, 6(3), 189–203. <https://doi.org/10.1162/jocn.1994.6.3.189>
- [32]. Landau, B., & Jackendoff, R. (1993). Whence and whither in spatial language and spatial cognition? *Behavioral and Brain Sciences*, 16(2), 255–265. <https://doi.org/10.1017/S0140525X00029927>
- [33]. Levinson, S. C. (2003). *Space in Language and Cognition: Explorations in Cognitive Diversity*. Cambridge University Press.
- [34]. MacSweeney, M., Woll, B., Campbell, R., Calvert, G. A., McGuire, P. K., David, A. S., Simmons, A., & Brammer, M. J. (2002). Neural Correlates of British Sign Language Comprehension: Spatial Processing Demands of Topographic Language. *Journal of Cognitive Neuroscience*, 14(7), 1064–1075. <https://doi.org/10.1162/089892902320474517>
- [35]. McCullough, S., Saygin, A. P., Korpics, F., & Emmorey, K. (2012). Motion-sensitive cortex and motion semantics in American Sign Language. *NeuroImage*, 63(1), 111–118. <https://doi.org/10.1016/j.neuroimage.2012.06.029>
- [36]. Mishkin, M., Ungerleider, L. G., & Macko, K. A. (1983). Object vision and spatial vision: Two cortical pathways. *Trends in Neurosciences*, 6, 414–417. [https://doi.org/10.1016/0166-2236\(83\)90190-X](https://doi.org/10.1016/0166-2236(83)90190-X)
- [37]. Molenberghs, P., Mesulam, M. M., Peeters, R., & Vandenberghe, R. R. C. (2007). Remapping attentional priorities: Differential contribution of



- superior parietal lobule and intraparietal sulcus. *Cerebral Cortex*, 17(11), 2703–2712. <https://doi.org/10.1093/cercor/bhl179>
- [38]. Montefinese, M., Pinti, P., Ambrosini, E., Tachtsidis, I., & Vinson, D. (2021). Inferior parietal lobule is sensitive to different semantic similarity relations for concrete and abstract words. *Psychophysiology*, 58(3). <https://doi.org/10.1111/psyp.v58.310.1111/psyp.13750>
- [39]. Newman, A. J., Supalla, T., Fernandez, N., Newport, E. L., & Bavelier, D. (2015). Neural systems supporting linguistic structure, linguistic experience, and symbolic communication in sign language and gesture. *Proceedings of the National Academy of Sciences*, 112(37), 11684–11689. <https://doi.org/10.1073/pnas.1510527112>
- [40]. Nichols, T., Brett, M., Andersson, J., Wager, T., & Poline, J.-B. (2005). Valid conjunction inference with the minimum statistic. *NeuroImage*, 25(3), 653–660. <https://doi.org/10.1016/j.neuroimage.2004.12.005>
- [41]. Noordzij, M. L., Neggers, S. F. W., Ramsey, N. F., & Postma, A. (2008). Neural correlates of locative prepositions. *Neuropsychologia*, 46(5), 1576–1580. <https://doi.org/10.1016/j.neuropsychologia.2007.12.022>
- [42]. Pyers, J. E., Perniss, P., & Emmorey, K. (2015). Viewpoint in the visual-spatial modality: The coordination of spatial perspective. *Spatial Cognition & Computation*, 15(3), 143–169. <https://doi.org/10.1080/13875868.2014.1003933>
- [43]. Quinto-Pozos, D., Singleton, J. L., Hauser, P. C., Levine, S. C., Garberoglio, C. L., & Hou, L. (2013). Atypical signed language development: A case study of challenges with visual-spatial processing. *Cognitive Neuropsychology*, 30(5), 332–359. <https://doi.org/10.1080/02643294.2013.863756>
- [44]. Sandler, W., & Lillo-Martin, D. (2006). *Sign Language and Linguistic Universals*. Cambridge University Press.
- [45]. Secora, K., & Emmorey, K. (2020). Visual-spatial perspective-taking in spatial scenes and in American Sign Language. *The Journal of Deaf Studies and Deaf Education*, 25(4), 447–456. <https://doi.org/10.1093/deafed/enaa006>
- [46]. Struiksma, M. E., Noordzij, M. L., Neggers, S. F. W., Bosker, W. M., & Postma, A. (2011). Spatial language processing in the blind: Evidence for a supramodal representation and cortical reorganization. *PLOS ONE*, 6(9). <https://doi.org/10.1371/journal.pone.0024253>. e24253.
- [47]. Struiksma, M. E., Noordzij, M. L., & Postma, A. (2009). What is the link between language and spatial images? Behavioral and neural findings in blind and sighted individuals. *Acta Psychologica*, 132(2), 145–156. <https://doi.org/10.1016/j.actpsy.2009.04.002>
- [48]. Tranel, D., & Kemmerer, D. (2004). Neuroanatomical correlates of locative prepositions. *Cognitive Neuropsychology*, 21(7), 719–749. <https://doi.org/10.1080/02643290342000627>
- [49]. Ward, D. B. (2006). *Deconvolution analysis of fMRI time series data* (pp. 1–109). Milwaukee, WI: Biophysics Research Institute, Medical College of Wisconsin.
- [50]. Zacks, J. M. (2007). Neuroimaging studies of mental rotation: A meta-analysis and review. *Journal of Cognitive Neuroscience*, 20(1), 1–19. <https://doi.org/10.1162/jocn.2008.20013>

