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COMPARING CORTICAL ACTIVITY DURING THE PERCEPTION OF TWO FORMS OF BIOLOGICAL MOTION FOR LANGUAGE COMMUNICATION.

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ABSTRACT

Speaking and fingerspelling words are dynamic, biological, visual activities that serve language communication. However, fingerspelling is a manual articulation of orthography, whereas the visible aspect of spoken language is a product of speech articulation. These two stimulus types provide a revealing contrast for examining the cortical substrate for language perception. Functional magnetic resonance imaging (fMRI) was used to investigate cortical activity due to viewing spoken (lipread) vs. fingerspelled words. In Experiment 1, young adults with prelingual-onset severe-to-profound hearing impairments were imaged. In Experiment 2, young adults with normal hearing and minimal previous experience with fingerspelling were imaged. In both participant groups, fingerspelling and lipreading activated regions of the superior temporal sulcus (STS). However, in the normal-hearing participants, fingerspelling activated fewer regions in the STS. In both participant groups, other activation was observed for fingerspelling, including several dorsolateral parietal areas. These results suggest that the perception of different forms of biological motion (spoken and fingerspelled) occurs in partially shared but partially distinct cortical networks, depending on linguistic significance/ experience of the perceiver.

1. INTRODUCTION

Studies comparing oral and manual languages provide evidence regarding effects of perceptual and linguistic experience on the cortical organization for perception of language. Studies investigating the cortical processing sites responsible for understanding manual language have primarily focused on examining native users of American Sign Language and have provided evidence that similar cortical sites are active in deaf, native signers viewing ASL as in normal hearing, native English users reading and listening to English [1,2,3]. These studies of native signers, along with the studies of visible and auditory spoken language [4,5,6,7,8] suggest that, at a relatively coarse level of analysis, the cortical organization of the language system is remarkably similar, despite substantial variation in the perceptual and linguistic experience of the perceiver.

In the current study, we focused on the cortical sites active during the visual recognition of spoken and manually encoded English words. We compared and contrasted the cortical activation resulting from viewing spoken and fingerspelled words. Fingerspelling is a manual encoding of orthography used by deaf individuals to communicate words that do not correspond to signs. Fingerspelling and lipreading provide a particularly interesting contrast for examining cortical processing of language: Fingerspelling and speech both convey American English and share the properties of being produced for communication via biological motion. However, fingerspelling represents a socially agreed-upon artificial code, whereas speech is an aspect of the communication system for which humans are biologically predisposed. Because individuals differ dramatically in their experience with reception of fingerspelling, this contrast also affords the opportunity to examine effects of lifelong perceptual experience on cortical activity.

Previous studies have demonstrated that speechreading activates cortical regions that include the superior temporal sulcus and the lateral surface of the superior temporal gyrus [4,5]. The cortical regions active when viewing fingerspelling have not, to our knowledge, been examined. We hypothesized that, given their shared stimulus properties and linguistic function, a similar pattern of cortical activity would be observed for speechreading and viewing fingerspelling. Experiment 1 investigated whether the perception of fingerspelled words results in a similar pattern of cortical activity as lipreading in deaf adults who are skilled at the reception of both stimulus types. Experiment 2 investigated whether the pattern of cortical activity for perception of fingerspelled word varied as a function of experience with fingerspelling.

2. EXPERIMENT 1

Experiment 1 was designed to 1) provide an initial description of the pattern of cortical activity while viewing fingerspelled words and 2) Compare this pattern of activity with the pattern of cortical activation while speechreading words.

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2.1 Methods

2.1.1. Participants

Participant (gender)	Age	Etiology	Pure tone avg. L – R	Age loss discovered	Lipreading Screening (words correct)
IH1(F)	25:10	Ototoxic Drug	98 – 102	18 mos.	59.5%
IH2(F)	22:4	Unknown	103 – 98	3 mos.	62.2%
IH3(F)	22:7	Unknown	101 – 97	13 mos.	35.4%
IH4(F)	24:8	Chicken pox and high fever	87 – 100	3 years	73.2%
IH5(M)	25:6	Spinal meningitis	120 –120	24 mos.	43.9%

Table 1: Detailed participant information

The five deaf participants (see Table 1) were all right-handed and had no self-reported learning disabilities, vision 20/30 or better and self-reported use of English as native language. They had bilateral early-onset sensorineural hearing impairment greater than 85 dB HL pure tone average across 500, 1000, and 2000 Hz. They were currently enrolled at California State University at Northridge and had been educated in a mainstream and/or oral program for years ≥ 8.Participants were screened to be skilled lipreaders, and they self-reported knowledge and use of fingerspelling.

2.1.2. Procedure

At least two experiments were performed per participant, a lipreading experiment and a fingerspelling experiment. In the lipreading experiment, a sequence of silently mouthed monosyllabic words (stimulus 'on' condition) was contrasted with a sequence of colored patterns overlayed on a still frame of the same talker's face (control condition). To maintain the participants' vigilence during scanning, they performed a one-back monitoring task. This task was chosen because it could be performed by either a linguistic or non-linguistic strategy and could therefore be performed by knowledgeable and naïve participants. The participants pressed a button when they detected an immediate repitition of the lipread words or colored patterns. In the fingerspelling task, a sequence of fingerspelled monosyllabic words was similarly contrasted with a sequence of colored shapes overlayed on a still frame of the signer's hand. The static control was chosen because we were interested in only examining cortical activation related to viewing the motions produced during the

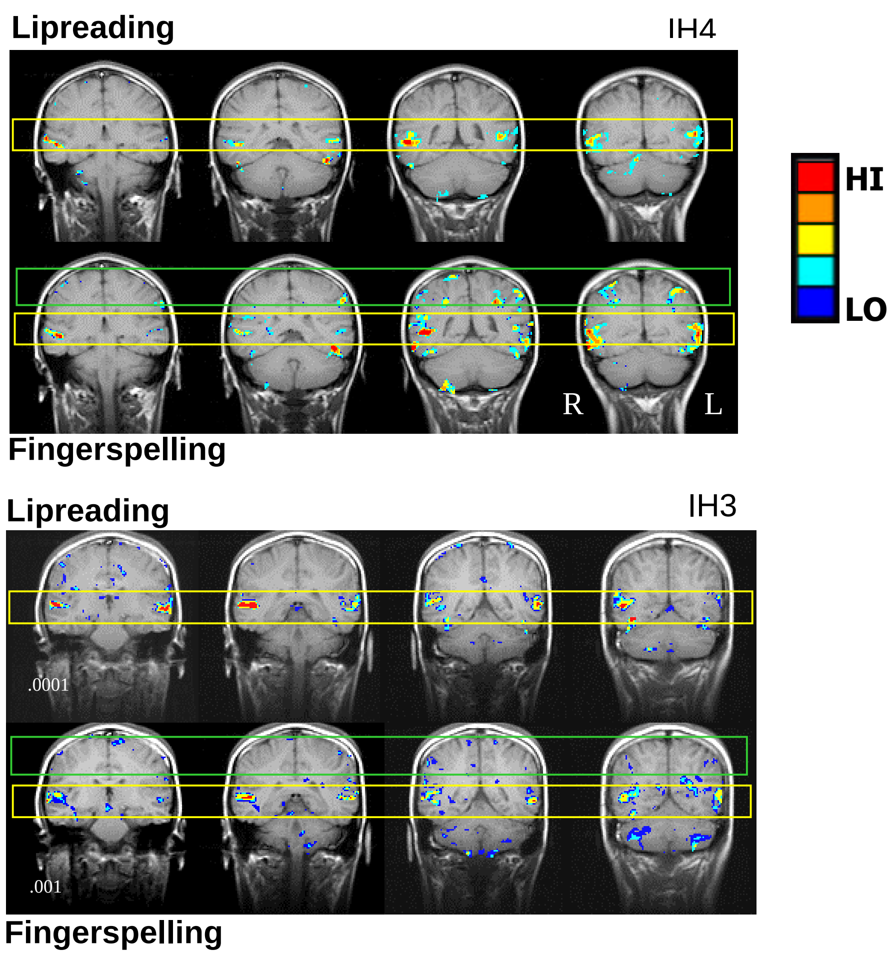

Figure 1. Four 10mm thick contiguous coronal slices showing activation during lipreading and fingerspelling for two deaf participants.

spoken or fingerspelling productions. The gradient sound was present equally during all conditions.

2.1.2. Data Acquisition

A GE 1.5T Signa Horizon MRI system with echo-planar imaging (EPI) was used to conduct the fMRI experiments. A quadrature head-coil was used to acquire a time-series of 500 images from four 10-mm thick contiguous transaxial or coronal sections (125 images per section) using an EPI sequence with the parameters: TR (repetition time) = 4s; effective TE (echo-time) = 45ms; 90 deg flip angle; 64x128 acquisition matrix; 20x40cm^2 field-of-view; and NEX (no. of excitations) = 1. Spin-echo anatomical images of the same sections were also acquired using TR = 400ms and TE = 14ms to obtain good gray/white-matter demarcation.

2.1.3. Image Analysis

The first five images per slice were ignored to establish equilibrium and starting at image 6, the task (e.g., lipreading or fingerspelling) and the corresponding control condition were presented in an alternating sequence for a total of 4 cycles. The time-series of images were co-registered to a reference image within the time-series using the method described in detail in [9]. Activated pixels were identified based on a statistical parameter mapping (SPM) approach, using the software package SPM99. A box-car reference function matching the task and control presentation sequence and delayed by one image (i.e., 4 sec) to account for hemodynamic delay was employed. The z-score of each pixel (defined as the average intensity difference between the task and control condition for a given pixel, divided by the standard deviation of its intensities during the control condition) was computed and pixels with z-scores above a threshold ($p < .001$) were identified. For each participant, activated pixels were color-coded according to their individual z-score and superimposed on corresponding anatomy.

2.2 Results and Discussion

Images clearly showed common regions of cortical activity while viewing spoken and fingerspelled words including Brodmann areas 21, 22, 37, & 39 (see yellow boxes in Figure 1). In four participants (IH2, IH3, IH4, & IH5), common activity was located in the STS. For IH1, common activity was located in the middle temporal gyrus. These regions activated by fingerspelling are consistent with regions observed in studies of both spoken and

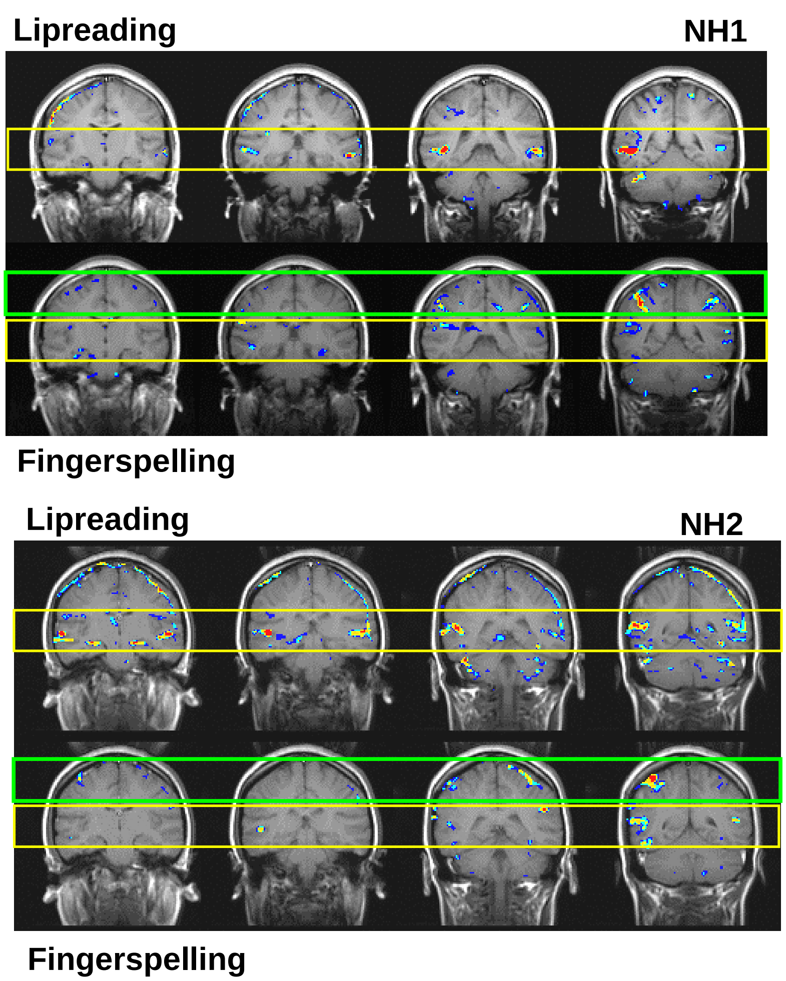

Figure 2. Four 10mm thick contiguous coronal slices showing activation during lipreading and fingerspelling for two hearing participants.

signed language[1,2,3,4,5,6,7,8].

In three participants (IH1, IH2, & IH4), several dorsolateral parietal area were strongly activated by viewing fingerspelled words (BA 7; see green boxes in Figure 1). These areas were not activated by lipreading. These areas are likely involved in the attention, perception, and memory for a sequence of hand motions[10,11,12,13].

Taken together, these results suggest that the perception of different forms of biological motion (spoken and fingerspelled) occurs in partially shared but partially distinct cortical networks.

3. EXPERIMENT 2

The majority of common activity observed in Experiment 1 was located in the STS. Regions of the STS have been demonstrated to be responsive to the perception of both biological motion and native spoken language [4,5,6,7,8,14,15]. At issue in Experiment 2 was whether linguistic and/or biological motion processing were responsible for the common regions of STS activity. One method for investigating is to vary the linguistic experience of the participants with the reception of fingerspelling. In Experiment 2, we used fMRI to investigate whether viewing fingerspelled words activates the same regions of STS in hearing lipreaders who had little or no previous experience perceiving fingerspelled words.

3.1 Methods

3.1.1. Participants

Seven individuals between 18 and 40 years of age; 6 right-handed and 1 individual with mixed handedness; no self-reported learning disabilities; no self-reported hearing loss, vision 20/30 or better; self-reported use of English as native language; above-average screened lipreading performance. Self-report of minimal or no previous experience in the reception of fingerspelling. One participant had learned about fingerspelling in grade school, but reported not understanding any of the words during the imaging session. One participant was not included due to minimal activity in both conditions at the $p < .001$ threshold.

3.1.1. Methods

All experimental procedures and imaging analyses were the same as in Experiment 1.

3.2 Results and Discussion

Images showed activation along the STS while viewing spoken words and fingerspelled words (see yellow boxes in Figure 2). However, in contrast to the results obtained in Experiment 1, the common activity was predominantly located in the most posterior regions of the STS. Taken together with the results of Experiment 1, the evidence suggests that the most posterior regions of the STS are responsive to biological motion, and the more anterior regions are responsive to linguistic attributes of the stimuli. This pattern of results is consistent with the literature on cortical activity for spoken language and for biological motion processing [8,14,15].

In all six participants, several dorsolateral parietal areas were strongly activated by viewing fingerspelled words (see green boxes in Figure 2). Viewing fingerspelled words also resulted in cortical activity in several parietal areas. These areas are likely involved in the attention, perception, and memory for a sequence of hand motions[10,11,12,13].

4. CONCLUSIONS

The results of these two experiments suggest that the perception of different forms of biological motion (spoken and fingerspelled) occurs in partially shared but partially distinct cortical networks, depending on linguistic significance/experience of the perceiver. Greater overlap in cortical activity was observed when both forms of biological motion were linguistically significant to the perceiver. This result suggests that previous observations of STS activity for lipreading were due to both biological motion processing and linguistic processing.

Based on results in the literature[10,11,12,13], we hypothesize that the presence of parietal activation could be due to a participant's processing strategy. For example, participants demonstrating parietal activity are likely attending to and remembering the sequence of hand motions and not using a linguistic coding of the stimulus. Alternatively, the recruitment of parietal regions may be related to task difficulty.

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6. REFERENCES

1. Bavelier, D., Corina, D. P., & Neville, H. J., Brain and language: a Perspective from sign language. *Neuron*, 21: pp. 275-278, 1998.
2. Neville, H. J., Bavelier, D., Corina, D., Rauschecker, J., Karni, A., Lalwani, A., Braun, A., Clark, V., Jezzard, P., & Turner, R., Cerebral organization for language in deaf and hearing subjects: Biological constraints and effects of experience. *Proc. Natl. Acad. Sci.*,95: pp. 922-929, 1998.
3. Soderfeldt, B., Ingvar, M., Ronnberg, J. Eriksson, L., Serrander, M., Stone-Elander, S., Signed and spoken language perception studied by positron emission tomography. *Neurology,* 49(1): pp. 82-87. 1997.
4. Calvert, G. A., Bullmore, E. T., Brammer, M. J., Campbell, R., Williams, C. R., McGuire, P.K., Woodruff, P. W. R., Iversen S. D., & David, A. S., Activation of auditory cortex during silent lipreading. *Science,* 276: pp. 593-596, 1997.
5. Bernstein, L. E., Auer, E. T., Moore, J. K., Ponton, C., Don, M. & Singh, M., Does auditory cortex listen to visible speech. *Cognitive Neuroscience Society, San Francisco, CA,* 2000.
6. Binder, J. R., Frost, J. A., Hammeke, T. A., Rao, A. M., & Cox, R. W., Function of the left planum temporale in auditory and linguistic processing. *Brain,* 119: pp. 1239-1247, 1996.
7. Binder, J. R., Frost, J. A., Hammeke, T. A., Bellgowan, P.S.F., Springer, J. A., Kaufman, J. N., & Possing, E.T., Human temporal lobe activation by speech and nonspeech sounds. *Cerebral Cortex,* 10: pp. 512-528. 2000.
8. Scott, S. K., Blank, C. C., Rosen, S., & Wise, J. S., Identification of a pathway for intelligible speech in the left temporal lobe. *Brain:* 123, pp. 2400-2406, 2000.
9. Singh, M., Al-Dayeh, L., Patel, P., Kim, T., Guclu, C., & Nalcioglu, O. Correction of head movements in multi-slice EPI and single-slice gradient-echo functional MRI. *IEEE Trans. Nucl. Sci.,* 45: pp. 2162-2167, 1998.
10. Bonda, E., Petrides, M. Ostry, D. & Evans, A., Specific involvement of human parietal systems and the amygdala in the perception of biological motion. *J. Neurosci.,* 16(11): pp. 3737-3744, 1996.
11. Gerardin, E., Sirigu, A., Lehericy, S., Poline, J.B., Gaymard, B, Marsault, C., Agid, Y., & Le Bihan, D., Partially overlapping neural networks for real and imagined hand movements. *Cerebral Cortex,* 10: pp. 1093-1104, 2000.
12. Buchel, C. Josephs, O., Rees, G., Turner, R., Frith, C. D., & Friston, K. J., The functional anatomy of attention to visual motion: A functional MRI study. *Brain,* 121: 1281-1294, 1998.
13. Iacobini, M. Woods, R. P., Brass, M. Bekkering, H., Mazziotta, J. C. , & Rizzolatti, G., Cortical mechanisms of human imitation. *Science,* 286: pp. 2526-2528.
14. Grossman, E., Donnelly, M., Price, R., Pickens, D., Morgan, V., Neighbor, G., & Blake, R., Brain areas involved in the perception of biological motion. *J. Cog. Neuro.*, 12(5): pp. 711-720, 2000.
15. Puce, A., Allison, T., Bentin, S., Gore, J. C., & McCarthy, G., Temporal cortex activation in humans viewing eye and mouth movements. *J. Neurosci.,* 18(6): 2188-2199, 1998.