

Dispersed activation in the left temporal cortex for speech-reading in congenitally deaf people

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Does the lateral temporal cortex require acoustic exposure in order to become specialized for speech processing? Six hearing participants and six congenitally deaf participants, all with spoken English as their first language, were scanned using functional magnetic resonance imaging while performing a simple speech-reading task. Focal activation of the left lateral temporal cortex was significantly reduced in the deaf group compared with the hearing group. Activation within this region was present in individual deaf participants, but varied in location from person to person. Early acoustic experience may be required for regions within the left temporal cortex in order to develop into a coherent network with subareas devoted to specific speech analysis functions.

Keywords: speech-reading; deafness; auditory cortex; functional magnetic resonance imaging

1. INTRODUCTION

When auditory speech is perceived a cortical network comprising regions within the lateral temporal lobes is activated. Activation is typically lateralized to the left hemisphere. According to a recent review (Binder 1999) a gradient of activation can be demonstrated over these regions. Cortical imaging techniques show that acoustic input activates the transverse temporal gyrus which incorporates the primary auditory cortex (BA41—Heschl's gyrus) (see, for example, Zatorre *et al.* 1992). A region neighbouring this area in the dorsolateral superior temporal gyrus (BA42) can be specifically activated by frequency-modulated tones (Binder *et al.* 2000). The more speech-like the auditory signal the more activation is observed in the ventral parts of the superior temporal gyrus and within the superior temporal sulcus (see Mummery *et al.* 1999). When the auditory task requires lexico-semantic processing, activation spreads to the middle temporal gyrus (BA21) and parts of the inferior temporal gyrus (BA20/37) (see, for example, Vandenberghe *et al.* 1996). This model suggests specific, contiguous locations for each of the stages of speech information processing (acoustic, segmental and lexical) which shows decreasing sensitivity to modality of input and increasing sensitivity to meaning. The trajectory of this shift is outwards to the lateral surface of the temporal lobe from the transverse temporal gyrus, then in a ventral direction from the mid-region of the upper lip of the superior temporal gyrus.

Assuming this model is substantially correct, to what extent is this pattern of specialization innate and to what extent determined by auditory and linguistic experience?

People born deaf into a hearing and speaking world offer a unique insight into this question. We report the results of a functional magnetic resonance imaging (fMRI) study of speech-reading in six congenitally deaf adults with English as a first language (oral deaf). These participants therefore acquired speech by eye.

When hearing people silently speech-read they show extensive activation of the lateral temporal cortex (Calvert *et al.* 1997; MacSweeney *et al.* 2000) including the lateral tip of Heschl's gyrus (BA41) and its neighbouring regions of the superior temporal gyrus, the presumed location of the secondary auditory cortex (BA42). Silent, seen speech therefore has the potential to activate parts of the speech-processing system that are usually thought to be modality specific. This could reflect learned associations between seen and heard speech so that, when there is repeated co-occurrence of a particular face movement with a particular acoustic experience, the multimodal percept reflects these contingencies. For example, audiovisual speech is more efficiently processed than heard speech alone (e.g. Massaro *et al.* 1993) and a natural audiovisual speech token generates greater activation within the primary auditory cortex than hearing speech in the absence of vision (Calvert *et al.* 1999). Under congruent audiovisual speech conditions, activation of the left superior temporal sulcus correlates with primary sensory cortex activation in both the visual and auditory systems (Calvert *et al.* 2000). The superior temporal sulcus therefore appears to have a role not only in multimodal processing of speech, but in modulating activation in other cortical areas. It may form part of a superior temporal system that binds coincident auditory and visual inputs into a unitary experience that retains modality-specific characteristics. This account suggests that a source of activation in Heschl's gyrus during silent

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speech-reading may be back-projections to this sensory area from the proposed binding site in the superior temporal sulcus (Calvert *et al.* 1999).

In people who were born deaf and who have not experienced audiovisual associations, we might anticipate reduced activation by speech-reading in the superior temporal sulcus as, in the absence of hearing, this region cannot function as a binding site. However, an alternative proposal is that the perception of speech, while normally reliant on auditory perception, nevertheless makes use of articulatory (gestural) representations (Liberman & Whalen 2000) and is processed in a fashion that is relatively insensitive to the modality in which it is perceived (i.e. direct realist approaches) (Fowler 1986). While gestural and direct realist approaches to speech perception have not committed to a specific neural substrate for the processing of speech segments, the left temporal cortex is a plausible candidate. If the specialization of the left lateral temporal cortex for speech is construed in this way, then deaf people who use speech may access the (left) lateral temporal speech-processing network despite a lack of acoustic input. Posterior parts of the superior temporal gyrus and superior temporal sulcus may be specialized for the phonetic analysis of speech, whatever the modality or modalities of input. From this psycholinguistic viewpoint, deaf people who use speech as their major language may share the cortical substrate for segmental speech perception with hearing people.

In this study, fMRI data were collected from hearing and congenitally deaf participants with profound hearing losses while they performed a simple speech-reading task (identifying randomly spoken numbers between one and nine). This task appears to be performed equally readily by hearing and deaf viewers (see Campbell 1998). Whole-brain coverage was obtained, but the focus of interest for this report was the lateral temporal cortex.

2. METHODS

(a) *Participants*

Twelve right-handed participants were tested. Six were normally hearing adults (two males and four females aged 21–55 years with a mean age of 30 years) and six were congenitally deaf (three males and three females aged 22–38 years with a mean age of 30 years). All subjects gave written informed consent to participate in the study which was approved by the Ethical Research Committee of the Maudsley Hospital. The hearing loss of each deaf participant was quantified using audiometry. The mean hearing level (HL) in the better ear of the deaf group was 110 dB HL (range 101–116 dB HL). All were therefore profoundly deaf at the time of testing and all reported being profoundly deaf since birth. All deaf participants had hearing parents and had consistently attended either mainstream schools where speech was their main form of communication or oral schools for the deaf which used speech-based teaching methods. Their dominant form of communication with hearing people in everyday life was through speech-reading. All deaf participants performed at or above an age-appropriate level on a test of non-verbal IQ (Block Design, Wechsler Adult Intelligence Scale—Revised). Educational level was closely matched across the two groups. Five deaf subjects and five hearing subjects had successfully completed tertiary education. A test of adult speech-reading (Ellis 1998) was administered to

the participants prior to the scan. The median score of the deaf participants tested was 93% (range 84–94%) ($n = 6$) while the median score for the hearing participants was 81% (three participants scored 80–93%, one participant scored 48% and two were not tested because of time limitations). Therefore, both the deaf and hearing participants were good speech-readers as measured by this test.

(b) *Experimental design*

The tasks were presented in alternating 21-s blocks of experimental and baseline conditions in a run lasting 4 min 54 s. The stimulus material comprised a silent video of a female speaker (including torso) with her full face looking straight at the camera.

(i) *Experimental condition: silent speech-reading*

Subjects viewed ten random numbers between one and nine being spoken at a rate of one every 2 s. Prior to entering the scanner each participant practised the speech-reading task with the experimenter. They then watched the speaker (the experimenter) on videotape and repeated each number aloud as they saw it being spoken. The participants performed the same task within the scanner but were instructed to repeat each number covertly rather than aloud. Both deaf and hearing participants reported that they found the task straightforward yet engaging.

(ii) *Baseline condition: still face*

The participants counted the number of times a digitally superimposed visual cue (a small black square) appeared on the chin of the static speaker's face. The task was performed aloud out of the scanner and covertly when in the scanner. The visual cue also appeared in the speech-reading condition but subjects were told to ignore it. The baseline condition thus controlled for attention to the face and for covert number naming.

The videotaped stimuli were projected onto a screen located at the base of the scanner table via a Proxima 8300 LCD projector (Proxima Corporation, San Diego, CA, USA). The image was projected to a mirror angled above the subject's head in the scanner. The visual angle of the speaker's head, subtended at the eye, was *ca.* 1°.

(c) *Imaging parameters*

Gradient echo echoplanar MRI data were acquired with a 1.5T General Electric Signa scanner (General Electric Medical Systems Europe, France) retrofitted with an advanced nuclear magnetic resonance operating console with a standard quadrature head coil. Head movement was minimized by positioning the subject's head between cushioned supports. Ninety-eight T2*-weighted images depicting bold contrast were acquired with a slice thickness of 7 mm (with a 0.7 mm interslice gap). Fourteen axial slices were acquired in each volume in order to cover the whole brain (repetition time = 3 s and echo time = 40 ms). An inversion recovery echo planar imaging data set was also acquired in order to facilitate registration of each individual's fMRI data set to Talairach space (Talairach & Tournoux 1988). This was comprised of 43 3-mm slices (3 mm gap) which were acquired parallel to the anterior commissure–posterior commissure line (echo time = 80 ms, inversion time = 180 ms and repetition time = 16 s).

(d) *Data analysis*

(i) *Analysis of data for each group*

Following motion correction, a least-squares fit was carried out between the observed time-series at each voxel and a mixture

Table 1. Brain regions active during speech-reading within each group relative to baseline

cerebral region (Brodmann area)	number of voxels	<i>p</i> -value	coordinates (mm)		
			<i>x</i>	<i>y</i>	<i>z</i>
hearing group					
left superior temporal gyrus (22)	23	< 0.000 05	-58	-3	4
left anterior cingulate (32)	14	< 0.000 05	-3	44	9
right middle temporal gyrus (21)	12	< 0.000 05	61	-19	-2
left precentral gyrus (4)	11	< 0.000 05	-49	-8	42
right superior temporal gyrus (22)	10	< 0.000 05	61	-22	4
left postcentral gyrus (3/2/1)	8	< 0.000 05	-46	-17	48
left middle temporal gyrus (37)	7	< 0.000 05	-49	-58	4
left superior temporal sulcus (22)	6	< 0.000 05	-61	-33	9
left middle temporal gyrus (21)	6	< 0.000 05	-61	-28	4
right Heschl's gyrus (41)	5	< 0.000 5	46	-19	15
left Heschl's gyrus/superior temporal gyrus (42)	5	< 0.000 05	-58	-3	9
right middle temporal gyrus (21)	5	< 0.000 05	46	-25	-2
deaf group					
cuneus (18)	12	< 0.000 5	0	-83	15
precuneus (31)	12	< 0.000 05	0	-58	20
left posterior cingulate (23)	9	< 0.000 05	-3	-56	15
left posterior insula	9	< 0.000 05	-35	-28	20
right parahippocampal gyrus (18)	7	< 0.000 5	23	-50	4
right frontal operculum (43)	7	< 0.000 05	43	-6	15
right postcentral gyrus (1/2/3)	6	< 0.000 05	38	-22	42
left parahippocampal gyrus (18)	6	< 0.000 05	-17	-50	4
right insula	6	< 0.000 5	43	-3	9
right postcentral gyrus (40)	5	< 0.000 05	46	-14	20
cuneus (18)	5	< 0.001	0	-72	15

of two one-parameter gamma variate functions (peak responses 4 and 8s) convolved with the experimental design (Friston *et al.* 1998). A modified *F*-statistic was derived from the ratio between the sum of squares due to the model fit and the residual sum of squares after removal of autocorrelations from the residuals. Significant values of this statistic were identified by comparison with its null distribution as computed by repeating the fitting procedure ten times at each voxel after random permutation of the time-series. This non-parametric procedure has been reliably validated for use in fMRI time-series analysis (Bullmore *et al.* 1996). The observed maps from each subject were transformed into Talairach space and median activation maps were computed separately for deaf and hearing groups after smoothing with a Gaussian filter (full width at half maximum 7.2 mm) at a voxel-wise probability of false activation of < 0.00125 (see table 1). Since the data were smoothed, it is possible that some type 1 error voxels may form clusters. In order to address this we conducted a bootstrap experiment in which 100 group data sets were constructed by randomly sampling, with replacement, from a null data set (no experimental paradigm) obtained from six subjects. The data set was analysed at each bootstrap at a fixed voxel-wise, type 1 error rate. The size of the largest cluster was stored after each analysis and the 95th centile of this distribution computed after termination of the bootstrapping procedure. At a voxel-wise, type 1 error rate of 0.001, the cluster size at the 95th centile of the distribution was four voxels. Therefore, in order to avoid unwarranted interpretation of activations that could be random type 1 errors, we report only clusters of greater than four voxels.

(ii) Group contrast analysis

Differences in the responses (*F*) of the deaf and hearing groups were inferred at each voxel level by regression of the generalized linear model $F = a_0 + a_1H + e$, where the vector *H* codes for hearing status and *e* is random error. Maps of the standardized coefficient (effect size) a_1^* were tested for statistical significance by a two-tailed test against a null distribution formed by a randomization procedure. Due to the large number of voxel locations tested, the estimated number of type 1 errors at reasonable statistical thresholds (*p*-values) is unacceptably large. Thus, spatial information was included, reducing the overall number of tests. Maps of a_1^* were thresholded such that only voxels passing $p < 0.05$ were retained. The sum of the suprathreshold voxel measures for each of the resulting two-dimensional clusters was then tested, with its sign indicating a relative excess or deficit in the response of one group. Significance testing of the clusters was again performed against a null distribution obtained through randomization (Bullmore *et al.* 1999).

3. RESULTS

The group analyses showed that the hearing participants activated the lateral temporal cortex bilaterally in response to speech-reading. However, no significant temporal activation was observed when the deaf were analysed as a group (see table 1 and figure 1). In order to explore whether these differences were significant, an ANOVA comparing activation in clusters of contiguous

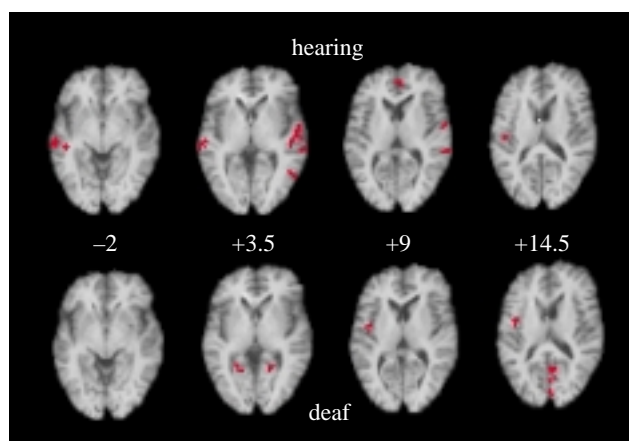


Figure 1. Median activation in response to speech-reading (red) in hearing ($n=6$) (top row) and deaf groups ($n=6$) (bottom row). Contiguous axial sections are shown from $z = -2$ mm to $z = 15$ mm. The data are shown superimposed on a high-resolution anatomical image in radiological convention so that the left of the image corresponds to the right hemisphere. In the hearing group speech-reading activated the superior temporal gyrus bilaterally (BA22). In the left-hemisphere Heschl's gyrus was activated at the lateral tip (BA42) (secondary auditory cortex) extending medially towards BA41. In the right-hemisphere Heschl's gyrus was activated at the medial portion (BA41) (primary auditory cortex). No temporal cortical activation was observed in the deaf group.



Figure 2. Clusters A and B represent clusters of voxels in which the level of activation differed significantly between groups. The clusters are shown on contiguous 5.5 mm axial slices from $z = -2$ mm to $z = 25.5$ mm. The left side of the image corresponds to the right hemisphere. Cluster A is right lateralized extending from the putamen ($x = 17$ mm, $y = 6$ mm and $z = -7$ mm) through the anterior part of the insula ($x = 35$ mm, $y = 8$ mm and $z = 9$ mm). This represents greater activation in the baseline condition in the deaf group than the hearing group. Cluster B is left lateralized and extends from the middle temporal gyrus (BA21) ($x = -58$ mm, $y = -28$ mm and $z = 4$ mm) through contiguous slices in the superior temporal gyrus (including BA22 and BA42) to the inferior parietal lobule (BA40) ($x = -55$ mm, $y = -25$ mm and $z = 26$ mm). This represents greater activation during speech-reading in the hearing group than the deaf group.

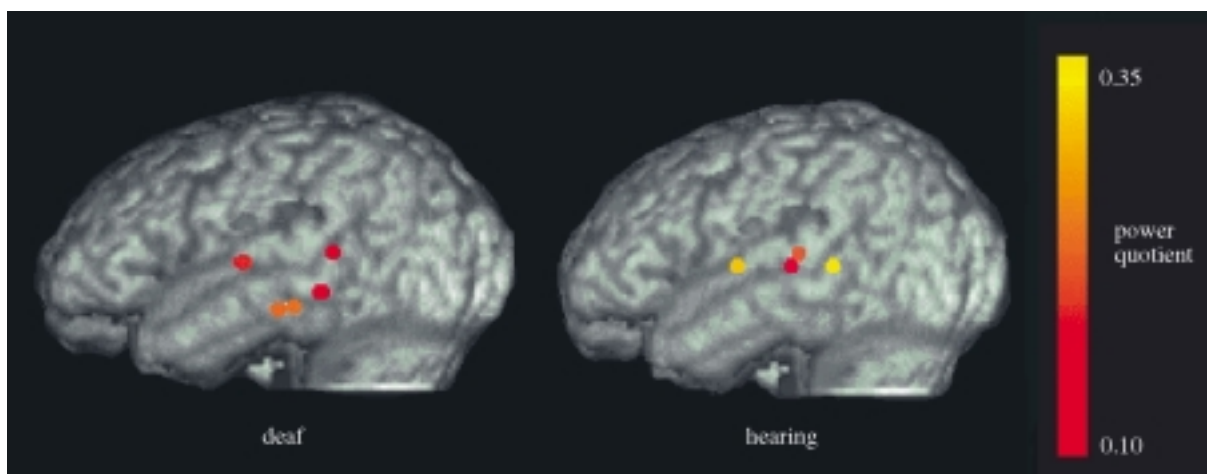


Figure 3. Locations of peak activation during speech-reading within the left temporal cortex. A separate marker represents each individual who showed significant activation within this region of interest. Each marker is colour coded to reflect the power of response at each focus of activation. The coordinates and significance levels of each of these responses are shown in table 2. These activations have been rendered onto an image of the lateral surface of a standardized brain.

voxels was performed (see §2(d)(ii)). Two clusters of voxels distinguished the groups (see figure 2).

Due to small sample sizes the group-contrast ANOVA did not incorporate phase information. Therefore, significant group differences have to be interpreted with reference to the median activation patterns of the deaf and hearing groups (see figure 1). The differential activation in the right insula region (cluster A) ($F_{1,10} = 23.7$ and $p < 0.002$) reflects differences in the baseline task and the deaf group activated this region more during the baseline

task than the hearing group. Of more interest in relation to our predictions was the between-group difference in activation within the left temporal cortex (cluster B) ($F_{1,10} = 15.5$ and $p < 0.004$). During speech-reading the hearing group showed greater activation than the deaf group in this region, which extends from the middle temporal gyrus (BA21) ($x = -58$ mm, $y = -28$ mm and $z = 4$ mm) through contiguous slices in the superior temporal gyrus (including BA22 and BA42) to the inferior parietal lobule (BA40) ($x = -55$ mm,

Table 2. *Foci of significant activations within the region of interest in the temporal lobes in each subject during speech-reading*
(An asterisk denotes the most powerful activations within the left hemisphere as plotted in figure 3.)

cerebral region (Brodmann area)	number of voxels	<i>p</i> -value	coordinates (mm)		
			<i>x</i>	<i>y</i>	<i>z</i>
deaf subject 1					
left superior temporal gyrus (22)*	9	< 0.000 05	-55	-6	4
left middle temporal gyrus (21)	5	< 0.000 05	-58	-19	-2
deaf subject 2					
right middle temporal gyrus (21)	16	< 0.000 05	46	-33	4
right superior temporal gyrus (42)	10	< 0.000 05	46	-33	9
left superior temporal gyrus (22)*	9	< 0.0001	-49	-36	9
right middle temporal gyrus (21)	5	< 0.000 05	49	-36	-2
deaf subject 3					
left middle temporal gyrus (21)*	8	< 0.0005	-61	-33	-7
right superior temporal gyrus (22)	6	< 0.0005	49	0	-2
right superior temporal gyrus (22)	5	< 0.001	58	-3	9
deaf subject 4					
no temporal activation	—	—	—	—	—
deaf subject 5					
left inferior temporal gyrus (20)*	18	< 0.000 05	-49	-22	-13
right superior temporal gyrus (22)	13	< 0.000 05	52	-39	9
right superior temporal gyrus (22)	9	< 0.000 05	61	-17	4
right superior temporal gyrus (22)	5	< 0.000 05	52	-36	15
deaf subject 6					
left middle temporal gyrus (21)*	11	< 0.000 05	-58	-19	-13
hearing subject 1					
left superior temporal gyrus (42)*	28	< 0.000 005	-55	-22	9
left superior temporal gyrus (22)	6	< 0.000 005	-52	-22	4
right middle temporal gyrus (21)	6	< 0.000 05	43	-36	4
left Heschl's gyrus (41)	5	< 0.0005	-43	-17	9
right middle temporal gyrus (21)	5	< 0.0001	55	-31	4
hearing subject 2					
right middle temporal gyrus (21)	13	< 0.000 05	49	-28	-2
right middle temporal gyrus (21)	8	< 0.0001	58	-28	-7
left superior temporal gyrus (22)	7	< 0.000 05	-64	-39	9
left middle temporal gyrus (21)*	7	< 0.000 005	-64	-36	4
hearing subject 3					
right middle temporal gyrus (21)	9	< 0.000 005	55	-47	4
right Heschl's gyrus (41)	5	< 0.0005	49	-17	15
left superior temporal gyrus (42/22)*	5	< 0.0005	-46	-19	4
hearing subject 4					
left superior temporal gyrus (22)	24	< 0.000 005	-61	-36	15
left superior temporal gyrus (42)	23	< 0.000 005	-64	-25	9
left superior temporal gyrus (42/22)	6	< 0.0005	-61	-36	20
right superior temporal gyrus (22)	5	< 0.0001	66	-22	4
left superior temporal gyrus (22)	5	< 0.000 005	-61	-17	4
right middle temporal gyrus (21)	5	< 0.000 05	64	-3	-2
left superior temporal gyrus (22)*	5	< 0.000 005	-58	0	4
hearing subject 5					
right superior temporal gyrus (22)	14	< 0.001	58	-19	4
hearing subject 6					
right inferior temporal gyrus (20)	12	< 0.000 005	40	-3	-29
right middle temporal gyrus (21)	7	< 0.0005	58	-19	-2

$y = -25$ mm and $z = 26$ mm). This analysis indicates that, although speech-reading in hearing people activates the temporal cortex bilaterally, the greatest difference between activation in the deaf and hearing groups was in the left temporal cortex.

The significant difference in left temporal activation between the deaf and hearing groups may reflect

subthreshold levels of activation in this region and/or variability in the topographic location of activation between individuals within this region in the deaf group. We therefore explored the topographic distribution of activation in each participant within the left lateral temporal cortex. Our region of interest included Brodmann areas 41, 42, 22, 21 and 20.

(a) Individual data: peak activation patterns in lateral temporal regions

Significant areas of activation within our region of interest were identified for each deaf and hearing participant (see table 2). Each participant's single most powerful significant response was selected from these activations (see figure 3). Left temporal activation was present in five deaf and four hearing participants. However, it appeared to be differently distributed according to hearing status. In three deaf subjects, peak activation was in differing parts of the middle or inferior temporal gyrus, while for three out of the four hearing participants peak activation occurred in overlapping and neighbouring parts of the superior temporal gyrus (central–posterior parts). The lack of significant temporal activation when the deaf were analysed as a group may not simply reflect reduced temporal activation in each deaf individual. Left temporal activation was present in most of them, but showed a more dispersed pattern. Statistical measures of spatial dispersion could not be used to test these differences reliably since they lack the necessary power with the numbers used in the current study.

4. DISCUSSION

The lateral temporal cortex was reliably activated bilaterally by speech-reading in the hearing participants, replicating our previous findings. In contrast, temporal activation in the deaf was not significant at the group level (table 1). Contrasts showed that this group difference was only significant in the left hemisphere; the deaf group showed significantly less left temporal activation than the hearing group. A more topographically dispersed pattern of left temporal activation in the deaf participants appeared to contribute to this difference. While most hearing subjects strongly activated the left superior temporal gyrus, in the deaf subjects peak activations tended to be in the left middle or inferior temporal gyrus.

It could be proposed that the group difference in left temporal activation may have reflected task differences as a function of hearing status. However, we argue that this is unlikely for the following reasons. Speech reading makes varying demands on its users, depending on the extent to which it is supported by acoustic information and the complexity of the verbal message imparted. Oral deaf people can be better speech-readers than hearing people when required to track a speech message reflecting semantic, pragmatic and syntactic constraints (Rönnerberg *et al.* 1999; Bernstein *et al.* 2000a). However, where context is tightly constrained ('a number between one and nine'), individual items are visibly distinctive and practice is given, speech-reading need not call on special skills other than those normally used to identify simple spoken words by deaf or hearing people. Previous work has failed to identify any differences between hearing and deaf speech-readers in the identification and storage of this sort of material (see Campbell 1998). Thus, it seems improbable, though not impossible, that the differences in cortical activation between deaf and hearing people in the present study reflected different task demands on the two groups.

As in our previous studies (Calvert *et al.* 1997; MacSweeney *et al.* 2000) the hearing participants

activated regions of the posterior superior temporal gyri bilaterally during speech-reading and also the left superior temporal sulcus. Activation was also observed at the lateral tip of Heschl's gyrus in the left hemisphere (BA42) ($x = -58$ mm, $y = -3$ mm and $z = 9$ mm) extending medially within the range of the primary auditory cortex. The medial portion of Heschl's gyrus in the right hemisphere was also activated. Activation of Heschl's gyrus in the right hemisphere has not been previously reported in speech-reading studies. One possibility is that, while activation in the superior temporal sulcus may precipitate activation in primary sensory areas, suprathreshold activation in these regions may be sensitive to the task and the participants tested. There were several differences between this and previously reported tasks which may have contributed to right-hemisphere activation in the current study—possibly the most important is the perceived size of the speaking face (1° in this study and 6° in Calvert *et al.* (1997)).

Data from Bernstein *et al.* (2000b) also raise the possibility that differences in the speech-reading task affect whether activation of the primary auditory cortex is found. Bernstein *et al.* (2000b) failed to find activation of the primary auditory cortex (functionally defined using a 1000-Hz pulse tone at a 5-Hz rate) during a speech-reading task. Hearing participants were required to monitor a stream of speech-read words for repetitions. These test conditions may be less conducive to 'reactivation' of the auditory cortex but more to the recruitment of visual cortical substrates to the task in order to compare the visual speech tokens. An important question for further research is to clarify the conditions under which the primary auditory cortex and other primary sensory processing areas may be activated by silent speech-reading and the nature of their functional involvement.

No deaf participant showed activation in the primary auditory cortex (BA41). This negative finding conforms with the likelihood that plasticity of this first acoustic projection region is limited. However, the present study does suggest that activation of the secondary auditory cortex (BA42) need not be confined to speech that is heard. One deaf subject showed marked activation of this region (deaf subject 2) (see table 2). However, since this was an isolated case, exposure to heard and seen speech appears to be required for more consistent activation of this region by silent speech.

A summary position with respect to the theories outlined in § 1 is that the left temporal cortex shows functional specialization for the perception of speech, which appears to be driven by exposure to acoustic input. When acoustic input is lacking from birth, this region does not show the expected pattern of focal specialization despite idiosyncratic activation within different temporal regions by individual deaf people when speech-reading.

5. CONCLUSION

The cortical localization of speech-reading depends on the hearing status of the speech-reader. The left temporal cortex is activated reliably in hearing people for a simple speech-reading task. In deaf people the extent of activation in these regions is relatively reduced, more variable

in location and less coherent with respect to a functional hierarchy of activation (Binder 1997, 1999; Binder *et al.* 2000). The corollary of this is that hearing speech helps to develop the coherent adult speech perception system within the lateral areas of the left temporal lobe. Thus, acoustic experience may shape but need not determine the specialization of networks within the left lateral temporal cortex for speech processing.

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