Supplementary Information for
Reading Modality Shapes Reading Network in Proficient Blind Readers of Braille

Mengyu Tian[a,1], Elizabeth J. Saccone[a], Judy S. Kim[a,b], Shipra Kanjlia[a,c], Marina Bedny[a]

[a] Department of Psychological and Brain Sciences, Johns Hopkins University, Baltimore, Maryland 21218

[b] Department of Psychology, Yale University, New Haven, Connecticut 06511

[c] Department of Psychology, Carnegie Mellon University, Pittsburgh, PA 15213

[1]To whom correspondence may be addressed: Email: mengyutian@jhu.edu

*Paste corresponding author name(s) here.
*Mengyu Tian
Email: mengyutian@jhu.edu

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Supplementary Method

Stimuli

The word stimuli consisted of 240 common nouns, verbs, and adjectives. Each participant was presented with 120 of the 240 words during the reading task; the other 120 words were presented auditorily during the listening task. The word lists were counterbalanced across participants. The Braille characters contain between 1-6 raised pins in set positions within a 2 x 3 array. In Grade-II contracted English Braille, there are contractions such that single Braille characters represent frequent letter combinations (e.g., "th") or frequent whole words (e.g., the "c" can stand for "can"). With contractions, the Braille words were on average 4 Braille characters (range = 1-8 Braille characters, SD = 2.1 characters) and 11 tactile pins per word. In the tactile consonant string condition, there were 24 strings repeated 5 times throughout the experiment. Each string stimulus consisted of 4 Braille letters, which were created using 20 English consonants. Last, the tactile control stimuli consisted of 24 unique strings of 4 non-letter shapes made of Braille pins. Note that any dot array within a 2 x 3 grid could be part of a Braille character. Therefore, to prevent participants from processing the shapes as Braille letters, the shapes varied in size and pin number within arrays ranging in size from 4 × 5 to 7 × 7. The average number of Braille pins per string in the control condition was 58.

For the sighted group, the word stimuli consisted of 240 common nouns, verbs, and adjectives that were on average 4 letters long (range = 3-5 letters, SD = 0.7 letters). Visual word stimuli consisted of a new set of words matched to the Braille words on average character length (i.e., 4 visual letters matched to 4 Braille characters), raw frequency per million, averaged frequency per million of orthographic neighbors, and averaged bigram frequency (all comparisons $p > 0.4$, obtained from the MCWord Orthographic Wordform Database)(1). Different groups of words were used for the visual and Braille experiment to enable character length matching since Braille contractions represent two or more English letters with a single Braille character. The visual consonant strings were the same 24 consonant letter combinations from the tactile consonant strings described above. Lastly, the control stimuli in the visual reading task were 24 unique strings, each comprised of 4 characters, which were false fonts. There were 20 false font characters in total, which matched the 20 English consonants on the number of strokes, presence of ascenders and descenders, and the stroke thickness. The stimuli for the listening task were taken from each group's respective word list. For the audio word condition, stimuli were 120 words taken from the reading task described above.

Procedure

For the blind participants, each trial began with a 0.5 s auditory cue instructing participants to "Touch' (reading trial), or "Listen" (listening trial). Then participants felt or heard blocks of 6 target items, one at a time. For 10 of the blind participants, tactile target stimuli were presented on the Braille display for 2 s, followed by a 0.75 s inter-stimulus interval (ISI) (6-item list duration: 16.5 s) (1). For the newly added 9 blind participants, the ISI was lengthened to 1.75 s due to a coding error which caused the 6-item list duration to be prolonged to 22.5 s. Control analyses revealed no effects of ISI duration on the results and the data are henceforth combined. After the 6-item list had been presented, there was a short delay (0.2 s), followed by a beep (0.5 s). Then a probe stimulus (2 s) was then presented, and participants indicated with a key press whether or not the probe had been present in the list. Participants had 5.3 s to make a response. The participants were asked to read with their dominant hand and responded with the other hand. The listening task was analogous in format to the reading task. The audio words and backward speech were on average 0.41 s long. The timing and sequence of events were identical for the listening task (6-item list duration 16.5 s).

For sighted participants, the trial event sequence (cue, 6-item block, beep, probe, response) was analogous to above. Each trial began with an auditory cue instructing participants to "Look" (reading trial) or "Listen" (listening trial). During reading trials, 6 visual stimuli appeared centrally for 1 s each, followed by an ISI of 0.75, during which participants were asked to maintain gaze on a black central fixation cross (total block duration: 10.5 s). Note that visual reading blocks were shorter than tactile reading blocks for the blind participants because pilot testing indicated that visual reading is faster under these conditions. Listening trials also had a total stimulus block duration of 10.5 s, to be consistent with the reading trials within the sighted group.

fMRI ROI analysis

To construct the left vOTC search space, we first combined the left fusiform, inferior temporal, and lateral occipital parcels from Freesurfer's automated aparc parcellation and then excluded V1, V2 regions, and the vertices with y-axis greater than -30 (2). To test the posterior-to-anterior function gradient, the left vOTC search space was divided to three portions: posterior (y < -64), middle (-48 > y > = -64), and anterior portion (y > = -48). The search space in the right hemisphere was created by flipping the left vOTC masks along the x-axis. The V1 search space was defined from a previously published anatomical surface-based atlas (PALS-B12) (3). The left inferior frontal language (IFC) search space was defined by using a sentence vs. non-words contrast from a previously published study (4). The parietal search space was defined by the orthogonal contrast of all tactile conditions (words, consonant strings, and control) > rest in whole-cortex analysis, excluding the occipital parcels from Freesurfer's automated aparc parcellation.

To avoid using the same data to define ROIs and to test hypotheses, a leave-one-run-out cross-validation procedure was used. ROIs were defined based on data from all but one run, then the percent signal change (PSC) was extracted from the left-out run. This procedure was repeated iteratively across all runs and the PSC was averaged across iterations.

Laterality index analysis

The bootstrap/histogram method was used to ensure that LIs were not overly influenced by arbitrary activation threshold choices or outlier voxels. Bootstrapped LIs were computed using 20 evenly spaced thresholds ranging from $z = 1.28$ to $z = 4.26$ (corresponding to one-sided $p = 0.1$ to $p = 0.00001$, uncorrected). For every threshold, each participant's z statistic map was masked to only include the voxels exceeding the threshold within the search space. Then we sampled the suprathreshold voxels 100 times with replacement in each hemisphere at a sampling ratio k = 1.0. The LIs were then calculated using each pair of left and right hemisphere samples, yielding a histogram of 10,000 threshold-specific LIs. Next, a single LI for each threshold was calculated by averaging the values after removing the upper and lower 25% of the 10,000 threshold-specific values. Finally, the LI reported for each participant represents the average across all thresholds.

A small number of participants were excluded from the LI analysis for a particular region if they did not have suprathreshold activation in both hemispheres (listening task- SMC: 2 sighted, 2 blind participants excluded; PPC: 1 sighted; V1: 6 sighted; IFC: 1 sighted; reading task- SMC: 4 sighted; PPC: 1 sighted; IFC: 1 sighted).

To examine the effect of spoken language lateralization and Braille reading handedness on the reading lateralization, a multiple regression was conducted for each region. The LI of spoken words in IFC and dominant reading hand were entered as regressors and the LI of written words was the dependent variable. Although some participants reported reading Braille bimanually, the participants were asked to read tactile stimuli during the experiment only with their dominant reading hand. There were 7 blind participants in the left Braille-reading handed group and 10 in the right Braille-reading handed group.

Topographical preference map

To partition the PPC into a series of sub-ROIs, we (1) draw a series of anchor points along the PPC mask; (2) fit a spline through the anchor points; (3) redefine the anchor points so that the spline is divided into 15 segments of equal distance; (4) draw a series of sub-ROIs with 25 mm radius centered on these anchor points, and then extract the overlap between each circle and the PPC mask; (5) remove the overlap between ROIs.

For consistency, the same procedure was performed for both the left and right PPCs. However, the left and right PPCs are defined by the group contrast of all tactile stimuli > rest, then the size and shape of these two masks are different. After removing the overlap between sub-ROIs, only 13 valid sub-ROIs were defined in the left PPC. Fifteen valid sub-ROIs were defined in the right PPC. In each sub-ROI, the mean beta value for each condition was extracted for each participant.

Supplementary Results

Behavioral results

Because the two groups differed in age, we regressed out the effect of age on accuracy and reaction times and performed analyses on the residuals (see Figure S1, results from raw data are also included in Figure S1). In the reading task, there was a significant effect of age on accuracy (main effect of age, $F_{(1, 85)} = 5.681$, $p < 0.05$). A two-way lexicality (words, consonant strings, control) by group (sighted, blind) ANOVA performed on the residuals revealed higher accuracy on more word-like stimuli (words and consonant strings > control) in both blind and sighted groups (main effect of lexicality: $F_{(2, 54)} = 13.963$, $p < 0.001$). There was no lexicality by group interaction ($F_{(2, 54)} = 0.872$, $p = 0.737$). The group effect was marginal (sighted > blind, $F_{(1, 27)} = 3.603$, $p = 0.068$). For the listening task, there was a trending effect of age on accuracy ($F_{(1, 56)} = 2.907$, $p = 0.094$). A two-way lexicality (words, control) by group (sighted, blind) ANOVA on the residuals revealed a lexicality effect (words > control; $F_{(1, 29)} = 50.944$, $p < 0.001$), no group effect ($F_{(1, 27)} = 0.843$, $p = 0.367$) or group by lexicality interaction ($F_{(1, 27)} = 0.549$, $p = 0.465$).

Likewise, for reaction times during the reading task, there was a significant effect of age ($F_{(1, 85)} = 39.089$, $p < 0.001$). A two-way lexicality (words, consonant strings, control) by group (sighted, blind) ANOVA on the residuals revealed a lexicality effect (words and consonant strings < control; $F_{(2, 54)} = 8.09$, $p < 0.001$). There was no group effect ($F_{(1, 27)} = 8.09$, $p = 0.297$). The group by lexicality interaction effect was marginal ($F_{(2, 54)} = 2.763$, $p = 0.072$). Pairwise comparisons showed shorter reaction times on more word-like stimuli in blind group, but there was no difference across stimuli in the sighted group (blind: words vs. control, $t_{(16)} = -2.91$, $p < 0.01$; consonant strings vs. control, $t_{(16)} = -2.604$, $p < 0.01$; words vs. consonant strings, $t_{(16)} = -0.686$, $p > 0.99$; sighted: all pairwise comparisons $p > 0.05$; the p-values were Bonferroni-corrected).

During the listening task, the main effect of age on reaction time was significant ($F_{(1, 85)} = 15.892$, $p < 0.001$). A two-way lexicality (words, control) by group (sighted, blind) ANOVA on the residuals revealed a lexicality main effect (words < control; $F_{(1, 29)} = 50.944$, $p < 0.001$). There was no group main effect ($F_{(1, 27)} = 0.071$, $p = 0.792$) or group by lexicality interaction ($F_{(1, 29)} < 0.001$, $p > 0.99$).

fMRI results: Visual (sighted) but not tactile Braille reading (blind) elicits a posterior-to-anterior functional gradient in left vOTC and shows left-lateralization

A four-way hemisphere (left, right) by posterior/anterior subregion (posterior, middle, anterior) by lexicality (words, consonant strings, control) by group (sighted, blind) ANOVA were conducted to examine reading responses across groups.

This ANOVA revealed significant main effects of hemisphere (left hemisphere > right hemisphere, $F_{(1, 32)} = 8.414$, $p < 0.01$), posterior/anterior subregion (posterior and middle > anterior, $F_{(2, 64)} = 9.74$, $p < 0.001$), and lexicality (words and consonant strings > controls, $F_{(2, 64)} = 14.31$, $p < 0.001$). There was no group main effect ($F_{(1, 32)} = 0.732$, $p = 0.399$). For the two-way interaction, the group by lexicality ($F_{(2, 64)} = 12.013$, $p < 0.001$), group by posterior/anterior subregion ($F_{(2, 64)} = 12.161$, $p < 0.001$), hemisphere by lexicality ($F_{(2, 64)} = 42.846$, $p < 0.001$) and the posterior/anterior subregion by lexicality ($F_{(4, 128)} = 9.237$, $p < 0.001$) interaction effects were significant. There was no hemisphere by group interaction effect ($F_{(1, 32)} = 0.748$, $p = 0.394$) or hemisphere by posterior/anterior subregion interaction effect ($F_{(1, 32)} = 1.44$, $p = 0.244$). For the three way interaction, the hemisphere by posterior/anterior subregion by group interaction ($F_{(2, 64)} = 3.72$, $p < 0.01$), the posterior/anterior subregion by lexicality by group interaction ($F_{(4, 129)} = 3.26$, $p < 0.05$), and the hemisphere by posterior/anterior subregion by lexicality interaction ($F_{(4, 129)} = 3.516$, $p < 0.01$) were all significant. Neither the hemisphere by lexicality by group interaction ($F_{(2, 64)} = 2.165$, $p = 0.123$) nor the hemisphere by posterior/anterior subregion by lexicality interaction were significant. The four-way interaction was reported in the main Results section.

For the sighted group, we found the expected three-way interaction between hemisphere (left, right), posterior/anterior subregion (posterior, middle, anterior) and lexicality (words, consonant strings, control; $F_{(4, 56)} = 4.287$, $p < 0.01$). Next, we looked at each hemisphere separately in the sighted group.

In the left vOTC, there was a two-way interaction between lexicality (words, consonant strings, control) and posterior/anterior subregion (posterior, middle, anterior; $F_{(4, 56)} = 9.69$, $p < 0.001$), reflecting the expected posterior-to-anterior functional gradient. Pairwise comparisons revealed that the posterior vOTC responded similarly to all visual stimuli (all pairwise comparisons $p > 0.05$). By contrast, in middle vOTC, consonant strings elicited higher responses than both words and control stimuli (Bonferroni-corrected paired *t*-test for words vs. consonant strings: $t_{(14)} = -3.918$, $p < 0.05$; consonant strings vs. control: $t_{(14)} = 4.106$, $p < 0.01$; words vs control: $t_{(14)} = 0.626$, $p = 0.542$). In anterior vOTC, responses to words and consonant strings were both higher than control and not different from each other (Bonferroni-corrected paired *t*-test for words vs. control: $t_{(14)} = 3.461$, $p < 0.05$; consonant strings vs. control: $t_{(14)} = 3.327$, $p < 0.05$; words vs consonant strings: $t_{(14)} = 0.108$, $p = 0.915$).

In the right vOTC of the sighted group, a two-way lexicality (words, consonant strings, control) by posterior/anterior subregion (posterior, middle, anterior) ANOVA revealed no main effect of lexicality ($F_{(2, 28)} = 0.448$, $p > 0.05$) and no interaction ($F_{(4, 56)} = 0.987$, $p > 0.05$). The main effect of posterior/anterior subregion was significant (anterior and middle < posterior; $F_{(2, 28)} = 8.146$, $p < 0.01$). To summarize, these results demonstrate that in the sighted group, there was a posterior-to-anterior functional gradient for processing word form during reading in the left but not right vOTC.

Next, we examined these effects in the blind group. We conducted a three-way hemisphere (left, right) by posterior/anterior subregion (posterior, middle, anterior) by lexicality (words, consonant strings, control) ANOVA. Unlike in the sighted, there was no significant three-way interaction ($F_{(4, 56)} = 0.877$, $p = 0.482$). Although there was no interaction, we conducted a separate ANOVA testing for a lexicality effect across the posterior/anterior subregions for each hemisphere separately in order to match the analysis of the sighted group.

In the left vOTC of the blind group, all three (posterior, middle, anterior) subregions responded most to words, followed by consonant strings followed by tactile shapes (Figure 1). There was a two-way interaction between lexicality (words, consonant strings, control) and posterior/anterior subregion (posterior, middle, anterior; $F_{(4, 72)} = 3.198$, $p < 0.05$). However, the nature of this interaction was different from that observed in the sighted group. All pairwise-comparisons between conditions were significant in all three subregions (words > consonant strings > control), except the difference between words and consonant strings did not reach significance in the anterior vOTC (Bonferroni-corrected paired *t*-test for words vs. consonant strings: posterior vOTC $t_{(18)} = 2.678$, $p < 0.05$; middle vOTC: $t_{(18)} = 3.166$, $p < 0.05$; anterior vOTC: $t_{(18)} = 2.016$, $p = 0.177$; words vs. control: posterior vOTC: $t_{(18)} = 5.463$, $p < 0.001$; middle vOTC $t_{(18)} = 8.547$, $p < 0.001$; anterior vOTC: $t_{(18)} = 5.874$, $p < 0.001$; consonant strings vs. control: posterior vOTC: $t_{(18)} = 3.413$, $p < 0.01$; middle vOTC $t_{(18)} = 4.696$, $p < 0.01$; anterior vOTC: $t_{(18)} = 5.034$, $p < 0.001$).

Unlike in the sighted group, in the right hemisphere of the blind group, lexicality effects were similar to the left hemisphere. All three (posterior, middle, anterior) subregions responded most to words, followed by consonant strings followed by tactile shapes. There was also a two-way interaction between lexicality (words, consonant strings, control) and subregion (posterior, middle, anterior; $F_{(4, 72)} = 7.064$, $p < 0.001$). Pairwise comparisons showed that the posterior right vOTC responded more to words than control ($t_{(18)} = 4.112$, $p < 0.01$); the middle vOTC responded more to words than both consonant strings ($t_{(18)} = 4.011$, $p < 0.01$) and control ($t_{(18)} = 4.819$, $p < 0.001$); and the anterior vOTC responded most strongly to words and consonant strings than control stimuli (words vs. consonant strings: $t_{(18)}$ = 2.429, p = 0.07; words vs. control: $t_{(18)}$ = 5.561, p < 0.001; consonant strings vs. control, $t_{(18)}$ = 4.522, p < 0.01). Other pairwise comparisons did not reach significance (posterior vOTC: words vs. consonant strings, $t_{(18)}$ = 2.349, p = 0.091; consonant strings vs. control, $t_{(18)}$ = 2.16, p = 0.134; middle vOTC: consonant strings vs control, $t_{(18)}$ = 2.073; p = 0.159).

For the listening task, similar to the reading task, we conducted a four-way hemisphere (left, right) by subregion (posterior, middle, anterior) by lexicality (words, control) by group (sighted, blind) ANOVA. The four-way interaction effect with group was marginal and we, therefore, did not proceed to further analyses ($F_{(2, 64)}$ = 2.717, p = 0.074). It is worth noting that in the sighted group, responses to auditory stimuli were below rest in posterior vOTC and above rest in the more anterior regions. This pattern was not observed in the blind group (see Figure S2).

fMRI results: V1 shows a preference for words in blind readers

We investigated the effects of lexicality across groups in V1 (Figure S4), because it was previously identified as relevant to Braille reading (Sadato et al., 1996; Cohen et al. 1997). As with vOTC, we first examined responses in left V1 during the reading task using the consonant strings > control functional ROIs. A two-way lexicality (words, consonant strings, control) by group (sighted, blind) ANOVA revealed main effects of lexicality ($F_{(2, 64)}$ = 4.247, p < 0.05) and group (sighted > blind, $F_{(1, 32)}$ = 6.964, p < 0.05). There was also a significant lexicality by group interaction ($F_{(2, 64)}$ = 9.487, p < 0.001). In the blind group, V1 responded most to words and there was no difference between consonant strings and control (Bonferroni-corrected paired *t*-test, words vs. consonant strings: $t_{(18)}$ = 2.641, p < 0.05; words vs. control: $t_{(18)}$ = 3.691, p < 0.01; consonant strings vs. control: $t_{(18)}$ = 2.367, p = 0.214). In the sighted group, V1 responded more to control stimuli than consonant strings (Bonferroni-corrected paired *t*-test, $t_{(14)}$ = 2.652, p < 0.01). There was no difference between other conditions (pairwise comparisons p > 0.05.) V1 responses in the blind group were similar when functional ROIs were defined using words > control (Figure S5). In the sighted group, however, a marginal preference for words over false fonts (control) emerged in this alternative analysis (Bonferroni-corrected paired *t*-test, $t_{(14)}$ = 2.573, p = 0.067; Figure S5). This latter result is consistent with some previous studies showing that V1/V2 responded more to words than non-letter control stimuli like scrambled words (5, 6).

For the listening task, the two-way lexicality (words, control) by group (sighted, blind) ANOVA showed a main effect of group ($F_{(1, 32)}$ = 16.067, p < 0.001), with overall greater activation seen in blind than sighted V1. There was no main effect of lexicality ($F_{(1, 32)}$ = 2.344, p = 0.316) and no interaction between the factors ($F_{(1, 32)}$ = 1.589, p = 0.217). Notably in the sighted but not blind group, responses to both words and audio control were below rest. This pattern of results was the same in words > control ROI (Figure S5).

fMRI results: No preference for words or consonant strings in primary sensory-motor cortex (SMC) hand region of blind participants

We examined responses of the left SMC hand region to test whether it showed a similar preference for Braille words and consonant strings as the PPC (Figure S4). For the reading task, the two-way lexicality (words, consonant strings, control) by group (sighted, blind) ANOVA showed a main effect of lexicality ($F_{(2, 64)}$ = 7.265, p < 0.001; functional ROIs were defined using the words > controls contrast), with higher responses to the consonant strings than control stimuli. Note that the responses to all stimuli were below rest in SMC in the blind group. There was no main effect of group ($F_{(1, 32)}$ = 0.604, p = 0.443) and no group by condition interaction ($F_{(2, 64)}$ = 1.501, p = 0.231). For the listening task, the two-way lexicality (words, control) by group (sighted, blind) ANOVA revealed a main effect of group ($F_{(1, 32)}$ = 15.622, p < 0.001), with overall greater responses in sighted group than blind group. There was no main effect of lexicality ($F_{(1, 32)}$ = 1.933, p = 0.174) and no interaction ($F_{(1, 32)}$ = 0.658, p = 0.423). Results were similar when the SMC ROIs were instead defined using the words > controls contrast (Figure S5). In sum, unlike in the PPC, we found no evidence for specialization of SMC for Braille reading as compared to perception of control tactile shapes.

fMRI results: The left inferior frontal cortex (IFC) prefers word-like written and spoken stimuli across blind and sighted readers

We analyzed responses in the left IFC across groups with the prediction that this high-level language region would show similar response patterns across blind and sighted readers. Consistent with this prediction, responses were similar across groups for both tasks in the left IFC (Figure S4). For the reading task, a two-way lexicality (words, consonant strings, control) by group (sighted, blind) ANOVA revealed a significant main effect of lexicality, with larger responses for words and consonant strings over the control condition ($F_{(2, 64)} = 46.313$, $p < 0.001$; functional ROIs were defined using the words > controls contrast). Neither the main effect of group ($F_{(1, 32)} = 0.004$, $p = 0.947$) nor the interaction ($F_{(2, 64)} = 1.017$, $p = 0.367$) were significant. Likewise, for the listening task, the two-way lexicality (words, control) by group (sighted, blind) ANOVA revealed the expected main effect of lexicality (words > control; $F_{(1, 32)} = 23.778$, $p < 0.001$). There was no main effect of group ($F_{(1, 32)} = 0.753$, $p = 0.392$) and no lexicality by group interaction ($F_{(1, 32)} = 0.357$, $p = 0.554$). There was also no group by condition interaction when functional ROIs were defined using the words > controls contrast. Both groups still showed a preference for words over control stimuli and in this case, there was also a larger response to words over consonant strings in both groups (Figure S5). These results are consistent with prior studies showing similar responses to spoken and written language in the left inferior frontal cortex of blind and sighted adults.

fMRI results: Lateralization of Braille correlates with spoken language lateralization and Braille-reading hand

First, we computed LIs separately for written (tactile/visual words > rest) and spoken (audio words > rest) language in the SMC, PPC, vOTC, V1, IFC and whole cortex in sighted and blind groups. On average, the sighted group's SMC, PPC and V1 activity was not systematically lateralized for written words (one-sample *t* tests of LI = 0, SMC: $t_{(10)} = 1.172$, $p = 0.268$; PPC: $t_{(13)} = 0.404$, $p = 0.692$; V1: $t_{(14)} = 1.614$, $p = 0.129$). For spoken words, we found right-lateralized activation in PPC and V1 for spoken words in the sighted group (one-sample *t* tests of LI = 0, PPC: $t_{(13)} = -3.161$, $p < 0.01$; V1: $t_{(8)} = -3.872$, $p < 0.01$). There were no systematic lateralization in SMC and whole cortex for the listening task (one-sample *t* tests of LI = 0, SMC: $t_{(13)} = -0.848$, $p = 0.412$; whole cortex: $t_{(14)} = 1.449$, $p = 0.169$). The blind group showed no systematic lateralization for written or spoken words in any region (one-sample *t* tests of LI = 0, reading: SMC: $t_{(18)} = 0.167$, $p = 0.869$; PPC: $t_{(18)} = -1.257$, $p = 0.225$; V1: $t_{(18)} = 0.735$, $p = 0.472$; whole cortex: $t_{(18)} = -0.166$, $p = 0.87$; listening: SMC: $t_{(13)} = -1.332$, $p = 0.206$; PPC: $t_{(18)} = 0.051$, $p = 0.96$; V1: $t_{(18)} = -0.506$, $p = 0.619$; whole cortex: $t_{(18)} = 0.395$, $p = 0.697$).

We then determined if lateralization of the Braille reading network could be predicted by the laterality of spoken language and Braille reading hand across blind individuals. A multiple regression analysis was conducted in each region, with the LI of spoken words in IFC and dominant reading hand entered as the regressors and the LI of written words as the dependent variable. First, both the dominant reading hand and the LI of spoken words in IFC predicted the LI of written words in PPC, vOTC and whole cortex (PPC: dominant reading hand: $\beta = 0.55$, $p < 0.001$; LI of spoken words in IFC: $\beta = 0.55$, $p < 0.001$; adjust $r^2 = 0.843$; vOTC: dominant reading hand: $\beta = 0.468$, $p < 0.01$; LI of spoken words in IFC: $\beta = 0.611$, $p = 0.001$; adjust $r^2 = 0.727$; whole cortex: dominant reading hand: $\beta = 0.399$, $p = 0.001$; LI of spoken words in IFC: $\beta = 0.534$, $p < 0.001$; adjust $r^2 = 0.761$). Second, in V1 and the IFC, only the LI of spoken words predicted the LI of written words (V1: dominant reading hand: $\beta = 0.258$, $p = 0.144$; LI of spoken words in IFC: $\beta = 0.734$, $p = 0.001$; adjust $r^2 = 0.575$; IFC: dominant reading hand: $\beta = -0.112$, $p = 0.359$; LI of spoken words in IFC: $\beta = 0.814$, $p < 0.001$; adjust $r^2 = 0.702$). Last, we found in SMC, only the dominant reading hand predicted the LI of written words (dominant reading hand: $\beta = 1.624$, $p < 0.001$; LI of spoken words in IFC: $\beta = 0.311$, $p = 0.261$; adjust $r^2 = 0.771$). To summarize, in blind individuals, responses to Braille written words and spoken words were co-lateralized to the same hemisphere across most of the Braille reading network, including the vOTC, V1, PPC, and the IFC. Braille reading hand also had an effect on the lateralization of Braille written words in vOTC, PPC, and SMC.

In the sighted group, we did not find the co-lateralization of spoken and written language to the same hemisphere. The correlation between the LI of spoken words in IFC and the LI of written words in vOTC was not significant (r = -0.233, p = 0.423). In addition, there were no correlations between the LI of spoken words in IFC and the LI of written words in V1, SMC or whole cortex (V1: r = -0.301, p = 0.296; SMC: r = 0.169, p = 0.62; whole cortex: r = 0.12, p = 0.683). However, the LI of spoken words in IFC was positively correlated with the LI of written words in PPC and IFC (PPC: r = 0.55, $p < 0.05$; IFC: r = 0.732, $p < 0.01$).

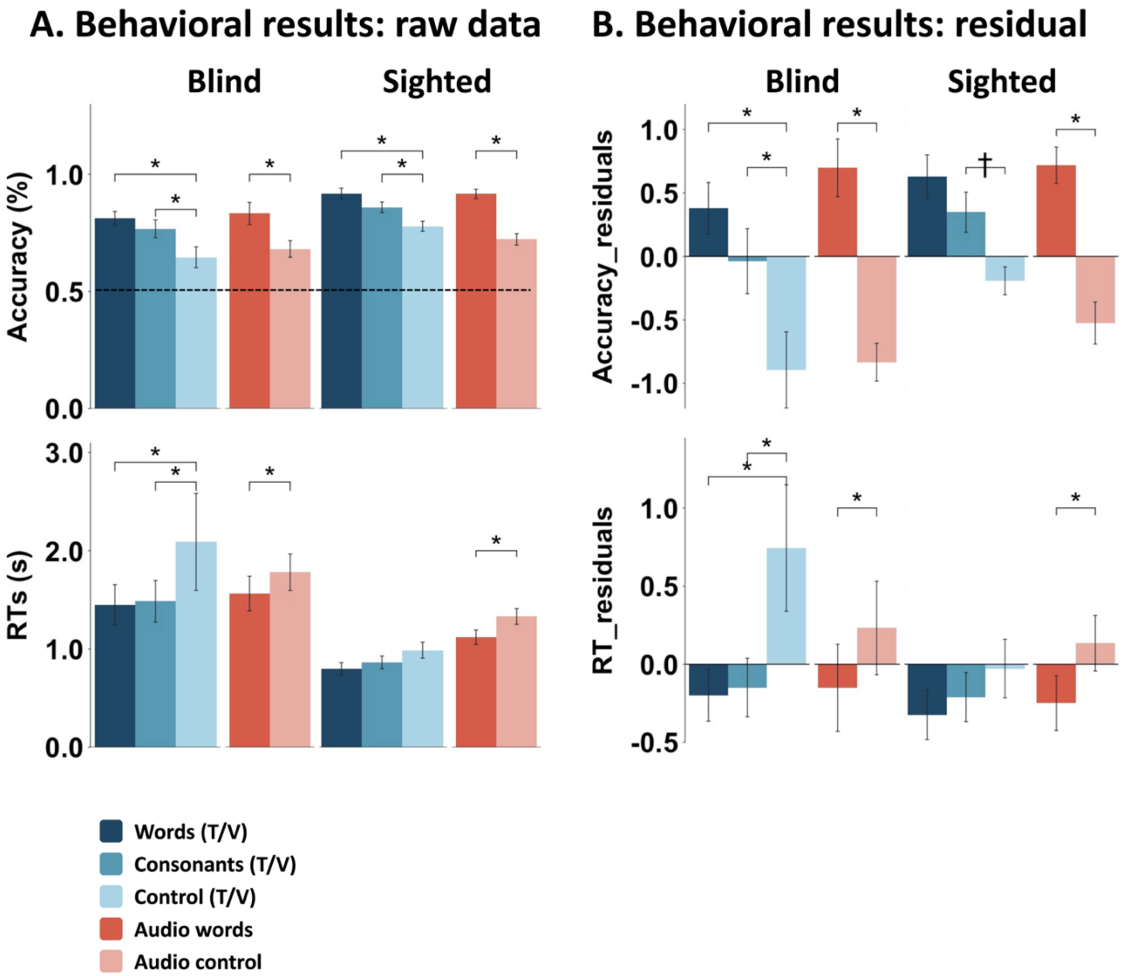

Fig. S1. A. Behavioral results. Raw accuracy (upper) and reaction time (lower) results for blind (left) and sighted (right) groups for reading (blue colors) and listening (orange colors) tasks. B. Because groups differed in age, age was regressed out prior to statistical comparison. The residuals after regressing out age for accuracy (upper) and reaction time (lower) for blind (left) and sighted (right) groups. Error bars denote standard errors +/- the mean. Asterisks (*) denote significant Bonferroni-corrected pairwise comparisons within task ($p < .05$). Cross (†) denote marginal difference in Bonferroni-corrected pairwise comparisons within task ($0.05 < p < 0.1$). T = tactile, V = visual, RT = reaction time.

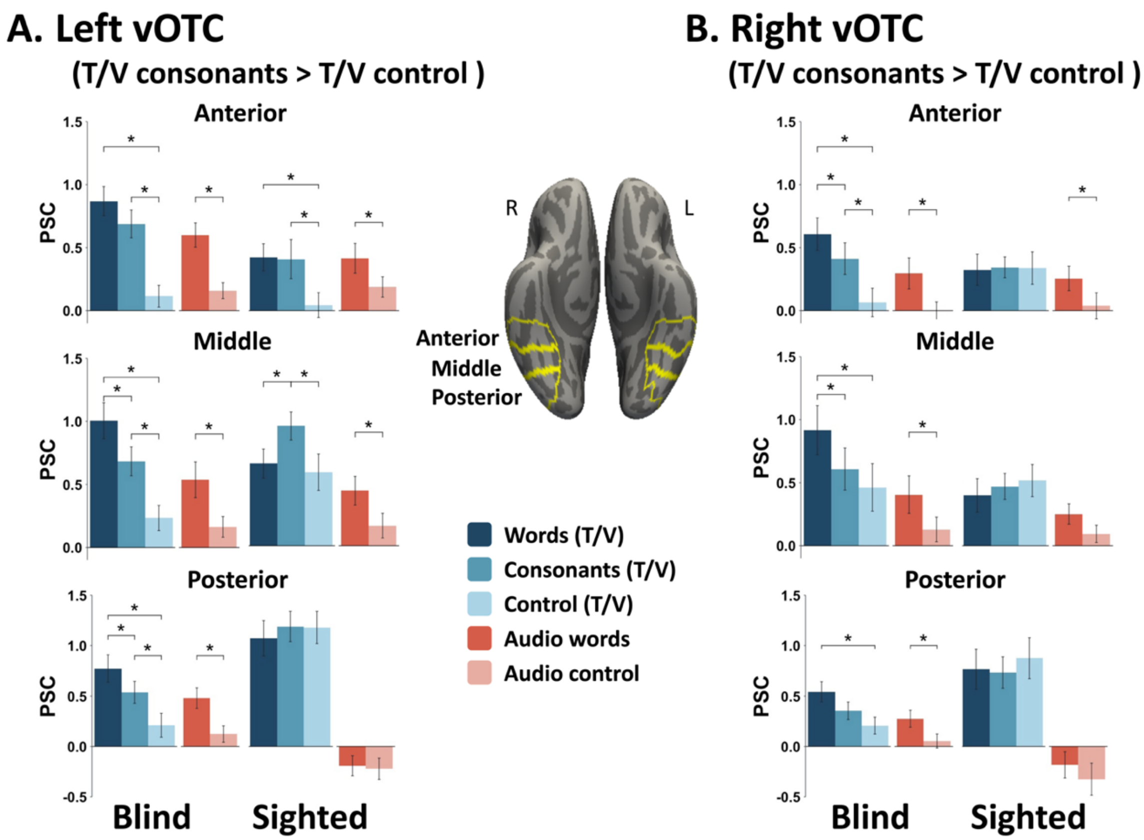

Fig. S2. Responses in (A) left and (B) right vOTC across posterior, middle and anterior subregions for blind and sighted groups during the reading (blue colors) and listening (orange colors) tasks using the consonant strings > control (false font/shape) contrast to identify individual functional ROIs (as reported in the main text). Error bars denote standard errors +/- the mean. Asterisks (*) denote significant Bonferroni-corrected pairwise comparisons within task (*p* <.05). T = tactile, V = visual.

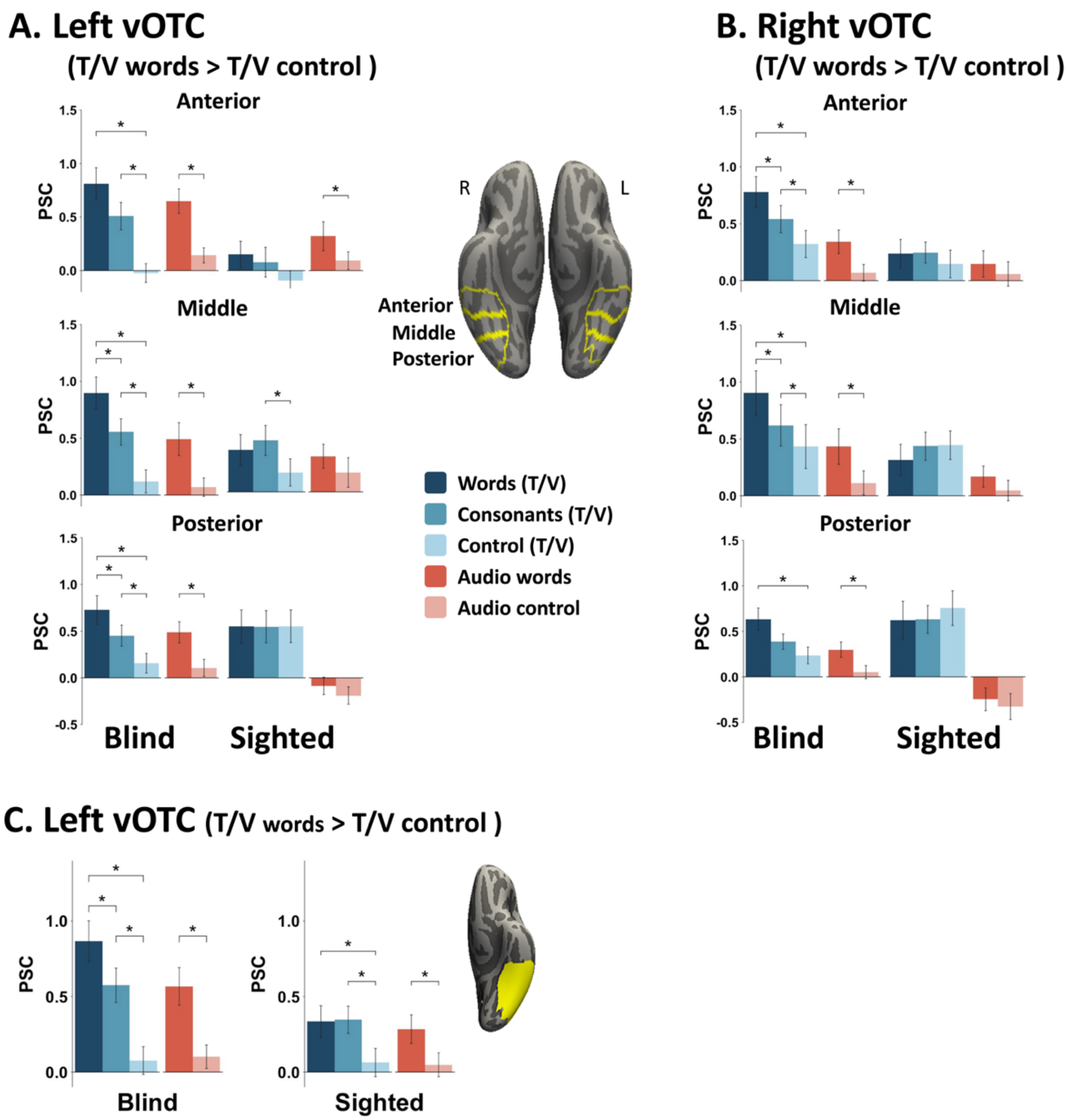

Fig. S3. Responses in (A) left and (B) right vOTC across posterior, middle and anterior subregions for blind and sighted groups during the reading (blue colors) and listening (orange colors) tasks using the words > control (false font/shape) contrast to identify individual functional ROIs. C. Error bars denote standard errors +/- the mean. Asterisks (*) denote significant Bonferroni-corrected pairwise comparisons within task (*p* <.05). T = tactile, V = visual.

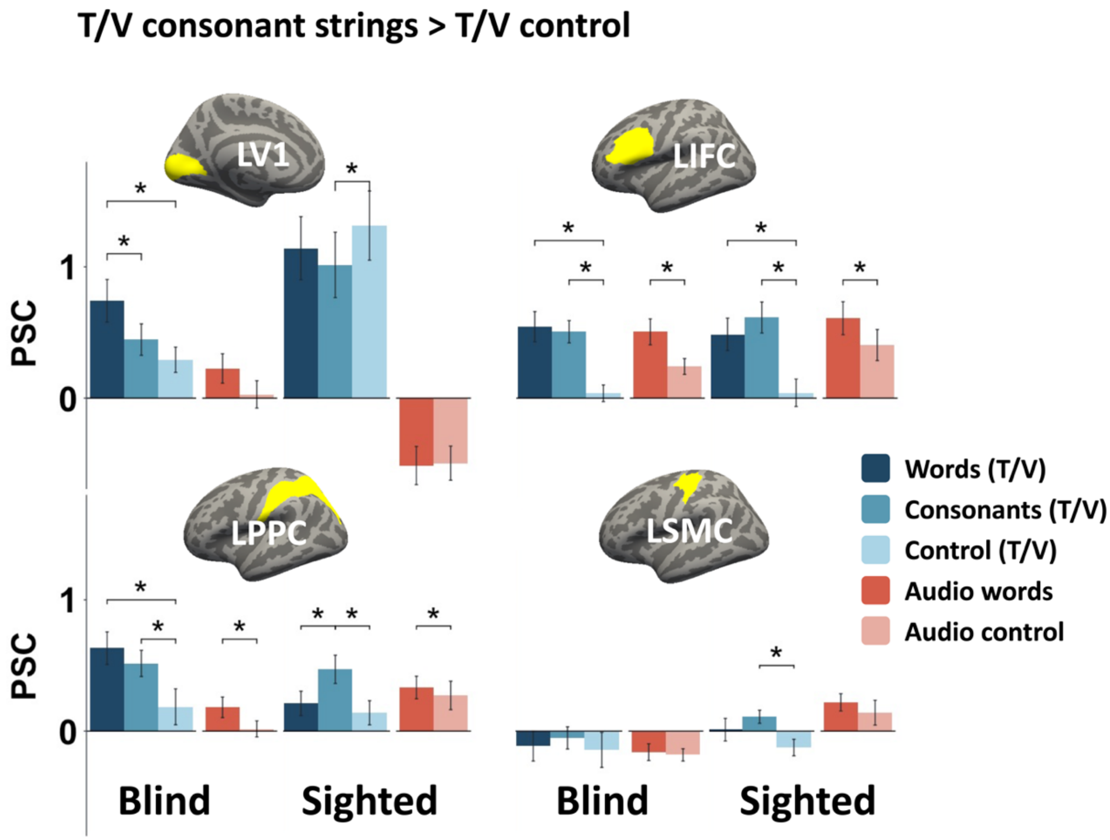

Fig. S4. Responses in left V1 (upper left), IFC (upper right), PPC (lower left), and SMC (lower right) ROIs for blind and sighted groups during the reading (blue colors) and listening (pink colors) tasks using the consonant strings > controls functional ROIs. Error bars denote standard errors +/- the mean. Asterisks (*) denote significant Bonferroni-corrected pairwise comparisons within task (p <.05). T = tactile, V = visual.

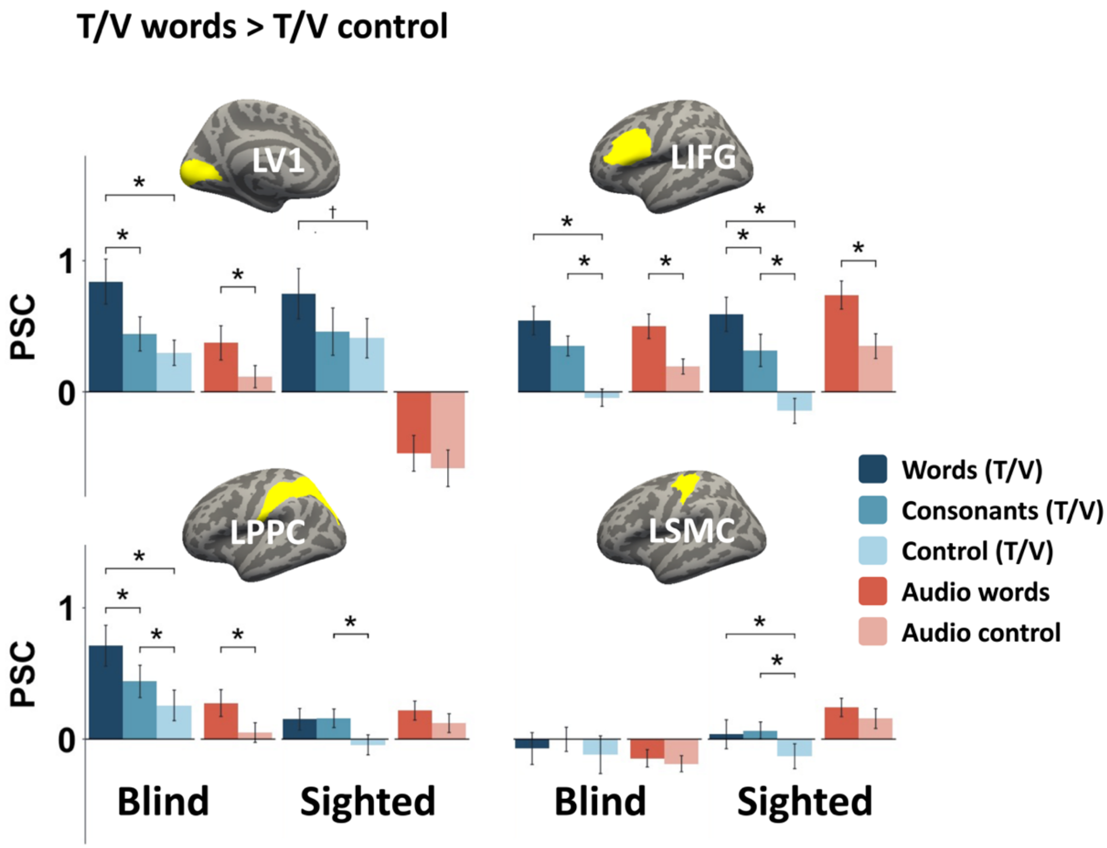

Fig. S5. Responses in left V1 (upper left), IFG (upper right), PPC (lower left), and SMC (lower right) ROIs for blind and sighted groups during the reading (blue colors) and listening (pink colors) tasks. Error bars denote standard errors +/- the mean. Asterisks (*) denote significant Bonferroni-corrected pairwise comparisons within task ($p < .05$). T = tactile, V = visual.

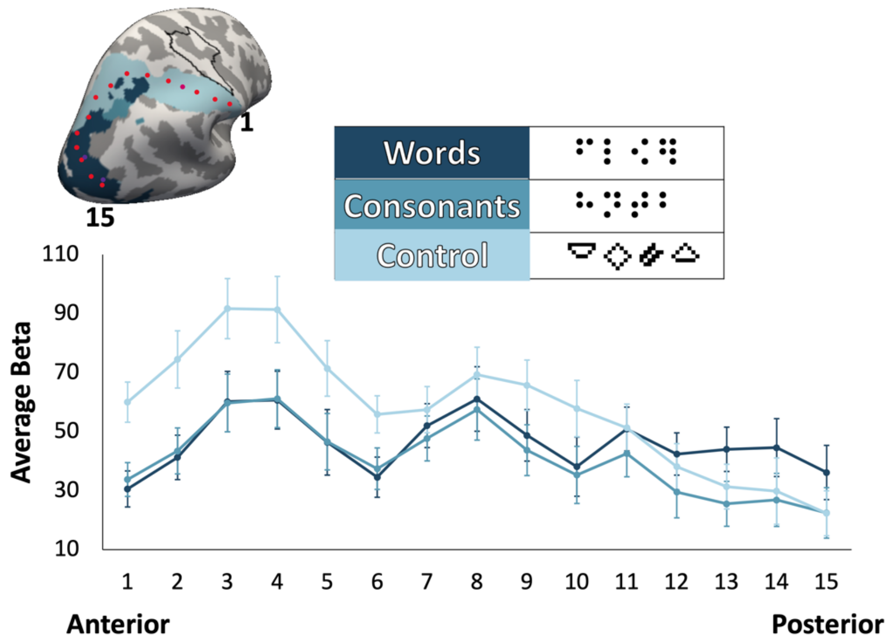

Fig. S6. Mean response to each reading condition along right anterior/posterior PPC extent in blind group (15 segments). Segment centers are marked by red dots.

Table S1. Participant information

Participant no.	Age (y)	Gender	Handedness	Reading handedness	Levels of education	Cause of blindness	Age started reading Braille (y)	Reading hours per week	Self-reported Braille reading ability (1-5)
B1	21	M	L	Bi-R	SC	LCA	4	14	5
B2	64	F	R	Bi-R	BA	ROP	6	56	5
B3	53	M	R	Bi-R	JD	LCA	6	7	4
B4	34	M	R	L	SC	Born without optic nerve	3	21	5
B5	42	M	Am	L	BA	ROP	3	21	5
B6	29	M	R	Bi-L	SC	LCA	4	<1	4
B7	39	F	R	L	BA	ROP	4	2	5
B8	34	F	R	--	SC	Optic Nerve Detached	3	--	5
B9	49	M	R	Bi-R	BA	unknown	8	<1	3
B10	26	F	R	Bi-R	MA	ROP	3	56	3
B11	49	F	L	R	MA	LCA	7	14	5
B12	39	F	R	L	MA	ROP	5	14	5
B13	35	F	R	Bi-L	MA	LCA	4	14	5
B14	46	F	R	--	BA	ROP	4	--	5
B15	33	F	R	L	BA	ROP	4	14	4
B16	25	F	Am	Bi-R	MA	LCA	5	56	5
B17	23	M	R	Bi-R	BA	LCA	4	28	5
B18	70	F	R	R	HS	ROP	7	7	4
B19	68	F	R	Bi-R	MA	ROP	5	7	5
Average									
Blind (n=19)	41 (SD=14.82)	12F	2L/2Am	--	BA	--	4.68 (SD=1.49)	19.47 (SD=18.97)	4.57 (SD=0.69)
Sighted (n=15)	23 (SD=6)	9F	1 L	--	BA	--	--		--

Handedness: left (L), ambidextrous (Am), or right (R), based on Edinburgh Handedness Inventory. BA = Bachelor of Arts; MA = Master of Arts; HS = High School; JD = Juris Doctor; SC = Some College; ROP = Retinopathy of prematurity; LCA = Leber's congenital amaurosis. For Braille ability, participants were asked: "On a scale of 1 to 5, how well are you able to read Braille, where 1 is 'not at all', 2 is 'very little', 3 is 'reasonably well', 4 is 'proficiently', and 5 is 'expert'?"

Table S2. Activated clusters in whole brain analysis

		Brodmann's areas	peak MNI coordinates			Peak z	Cluster size	
			X	Y	Z		vertices	mm^2
Blind								
Braille words > rest								
Left hemisphere	Lateral/posterior occipital cortex (inferior occipital gyrus)	19	-42	-73	-4	5.56	4502	8919.30
	Foveal confluence (middle occipital gyrus)	18	-26	-91	14	4.74		
	Pericalcarine cortex/lingual gyrus	17,18	-10	-82	3	4.67		
	Fusiform gyrus/inferior temporal gyrus	37,21	-41	-57	-13	4.98		
	Parieto-occipital cortex (middle occipital gyrus)	18,19	-20	-86	21	4.83		
	Superior parietal lobule	7	-33	-48	45	5.45		
	Supramarginal gyrus/postcentral gyrus	7	-41	-40	39	4.18		
	Precentral gyrus	6	-52	-2	42	5.11	784	1539.74
	Inferior frontal gyrus (Pars opercularis)	46	-41	26	15	3.46		
	Middle frontal gyrus	46	-43	26	26	3.76		
Right hemisphere	Superior parietal lobule	7	19	-60	57	5.56	4502	8919.30
	Supramarginal gyrus/postcentral gyrus	2,40	55	-23	35	5.01		
	Parieto-occipital cortex (superior occipital gyurs/middle occipital gyrus)	19,18	24	-80	32	4.89		
	Fusiform gyrus/inferior temporal gyrus/middle temporal gyrus	37	28	-42	-20	4.62		
	Pericalcarine cortex/lingual gyrus	17,18	7	-71	7	4.09		
	Precentral gyrus/ Inferior frontal gyrus (Pars opercularis)	6,44	-52	-2	42	5.11	784	1539.74

Auditory words > rest

Left hemisphere	Superior temporal gyrus/transverse temporal gyrus/middle temporal gyrus	38,39,22,42	-47	0	-18	6.02	4385	9057.87
	Fusiform gyrus	37	-42	-44	-16	5.29		
	Lateral occipital cortex	19,18	-41	-69	-1	4.77		
	Lingual gyrus/cuneus cortex/pericalcarine cortex	17,18	-3	-82	1	4.1		
	Inferior frontal gyrus (Pars opercularis)/middle frontal gyrus	44, 6	-52	14	14	4.99	286	579.34
	Inferior frontal gyrus (Pars triangularis)/ lateral orbitofrontal gyrus/insula	47, 45	-39	31	0	4.45	344	681
Right hemisphere	Superior temporal gyrus/transverse temporal gyrus	38,22,42	49	-13	-6	6.39	2659	5254.77
	Middle temporal gyrus	39	53	-61	4	4.24		
	Fusiform gyrus	37	41	-53	-15	4.9		
	Lateral occipital cortex	19	41	-70	2	4.22		
	Pericalcarine cortex/lingual gyrus	17,18	19	-72	6	4.44	2443	2233.19
	Inferior frontal gyrus (pars triangularis)/insula	45,46,47	43	30	1	4.94	914	1711.78
	Inferior frontal gyrus (Pars opercularis)/precentral gyrus	44,45,6	51	12	16	3.82		

Braille words > audio words

Left hemisphere	Inferior parietal lobule/parieto-occipital cortex (superior occipital gyurs/middle occipital gyrus)	19,18	-22	-77	29	5.69	2478	4291.01
	Superior parietal lobule	7	-37	-49	51	5.22		
	Supramarginal gyrus/postcentral gyrus	2,40	-39	-31	36	4.56		
	Fusiform gyrus	37	-27	-61	-14	4.81	277	720.98
	Lateral occipital cortex/inferior temporal gyrus	37,19	-44	-67	-5	4.28	378	659.90

	Pericalcarine cortex/lingual gyrus/cuneus cortex	17,18	-15	-93	-1	4.72	408	887.05
	Superior frontal gyrus	4,6	-10	-6	62	4.17	749.48	462.90
Right hemisphere	Superior parietal lobule	7	20	-59	58	6.00	2721	4268.20
	Supramarginal gyrus/postcentral gyrus	2,40	52	-27	40	5.53		
	Parieto-occipital cortex (superior occipital gyurs/middle occipital gyrus)	19	21	-68	41	5.49		
	Superior frontal gyrus	6	10	1	51	5.6	794	1414.74
	Precentral gyrus	4	31	-13	58	4.84		

Sighted

Visual words > rest

Left hemisphere	Foveal confluence (inferior occipital gyrus)	18,19	-33	-79	-11	6.38	1979	4440.12
	Lingual gyrus/pericalcarine cortex	17,18	-5	-93	-6	5.00		
	Fusiform gyrus/inferior temporal gyrus	37	-41	-58	-12	4.87		
	Precentral gyrus	4,6	-46	2	44	4.62	1268	2439.15
	Inferior frontal gyrus (parstriangularis/parsobitails)	45,47,11	-38	27	3	4.00		
	Inferior frontal gyrus (parsopercularis)/middle frontal gyrus	44,46	-44	22	20	3.93		
	Middle temporal gyrus/superior temporal gyrus	22	-62	-48	-1	3.88	306	536.40
	Inferior parietal lobule/superior parietal lobule	7	-27	-64	34	3.92	334	492.90
Right hemisphere	Calcarine/ Foveal confluence		25	-94	1	6.54	1661	4104.98
	Fusiform gyrus/inferior temporal gyrus	19,37	35	-71	-13	4.21		

Audio words > rest

Left hemisphere	Superior temporal gyrus/middle temporal gyrus	22,42,38	-60	-32	1	5.2	1664	3407.43

	Superior parietal lobule/postcentral gyrus	1,2	-31	-41	52	4.09	646	1054.27
	Inferior frontal gyrus (parstriangularis/parsobitails)	45,47,11	-39	39	-3	4.19	460	933.74
	lateral orbitofrontal gyrus	11	-39	28	-15	3.59		
	Inferior frontal gyrus (parsopercularis)/middle frontal gyrus	46,44	-44	19	19	4.51	389	745.81
	Precentral gyrus	4,6	-59	-0	25	2.29		
	Postcentral gyrus/ Supramarginal gyrus	2,43,41	-63	-11	16	4.39	445	776.02
Right hemisphere	Superior temporal gyrus/middle temporal gyrus	22, 42, 38,	61	-25	1	5.52	1559	3174.32
Visual words > audio words								
Left hemisphere	Lingual gyrus/ pericalcarine cortex	17,18	-19	-85	-9	6.07	1762	4000.01
	Lateral occipital cortex/fusiform gyrus/interior temporal cortex	19,37	-32	-79	-13	5.34		
	Superior parietal lobule/inferior parietal lobule		-26	-54	42	4.09	470	745.24
Right hemisphere	Lateral occipital cortex/fusiform gyrus	18,19,37	20	-89	-6	6.19	1589	3973.58
	Pericalcarine cortex/ lingual gyrus	17,18	16	-92	-1	5.63		

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