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Supplementary Materials for

Learning to read recycles visual cortical networks without destruction

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This PDF file includes:

Supplementary Text

The relationship between literacy and cortical selectivity for orthographic stimuli

In order to examine how specific to non-words the visual stream response is, we contrasted non-words with all the other categories of visual stimuli presented in the visual runs. These contrasts were then correlated with literacy in order to determine the loci where the difference between brain response to letters and other visual categories was enhanced by literacy (fig. S3). We expected this analysis to reveal significant peaks in correlation in the vicinity of the VWFA, which despite showing responses to categories of visual stimuli other than non-words and sentences, should exhibit an increasing degree of selectivity for these with the acquisition of literacy. There is clear convergence such that the magnitude of the contrast between responses to non-words and other inputs is modulated by literacy in not only the left fusiform gyrus, but also the left premotor cortex and left inferior frontal gyrus. This is consistent with the brain response to the tested categories of visual input in these areas being up-modulated by literacy for non-words but not for other categories. Since no negative relationship between literacy and brain responses to the stimuli presented was found in the left fusiform gyrus, left premotor cortex nor the left inferior frontal gyrus, this is likely due to the increased response to non-words with literacy.

The extent of category-selective regions evaluated by annular analysis

In addition to examining the relative magnitude of response in the vicinity of the VWFA, we also tested whether the spatial extent of the representation of the categories: Faces, Houses and Tools is affected by literacy, we conducted analyses of specificity inspired by those of (*7*) , themselves derived from a previous analytical approach (*27*) to the evaluation of visual cortical category selectivity. These were executed on data smoothed using a 4mm Gaussian kernel as follows: for a given contrast that can be said to reveal a category-specific response (for example: "Face > House"), individual subjects' peak within 10, 20, 30 and 40mm of the VWFA were determined. These then served as the centres for annular analysis, in which the mean response for the category in question vs baseline was extracted for a series of increasingly distant shells of voxels. For each shell, the average magnitude of responses to the category under investigation was tested for a relationship with reading proficiency.

If the hypothesis that literacy impinges upon the size of regions sensitive to houses and faces holds, then a negative relationship between literacy and brain response should become apparent at some distance from the individual peaks, since sensitivity to letter-strings will have supplanted other categories. These analyses showed no such relationships between mean brain response and literacy, for any annulus. This result is consistent with the extent of category-responsive cortex being unaffected by having learned to read in childhood. Specifically:

a) Peak for the Faces vs Houses
No significant relationships were found between literacy and response to faces compared to baseline at any annular radius from individually defined peaks, at 10mm, 20mm, 30mm or 40mm from the group VWFA.

b) Peak for Houses vs Faces

As for the Faces vs Houses peaks, no significant relationships were found between literacy and responses to houses compared to baseline at any annular radius from individually defined peaks within 10mm, 20mm, 30mm or 40mm of the group VWFA.

c) Peak for Tools vs Houses

Despite the absence of a known category-specificity for tools in visually-sensitive areas, for consistency with (*7*), we also tested whether any impact of literacy was apparent. For individual peaks situated within 10mm of VWFA, we found no significant relationship between literacy and brain response. For peaks within 40mm, a relationship appeared at a annular radii of 1 voxel (slope = 0.027, $t_{(89)}$=2.071, p=.041), 2 voxels (slope = 0.020, $t_{(89)}$=2.078, p=.041), 7 voxels (slope = 0.010, $t_{(89)}$=2.054, p=.043), 8 voxels (slope = 0.009, $t_{(89)}$=2.146, p=.035).

The results of these annular analyses provide no evidence for the idea that literacy negatively affects the extent of the cortical representation of various visual categories.

Fig. S1.

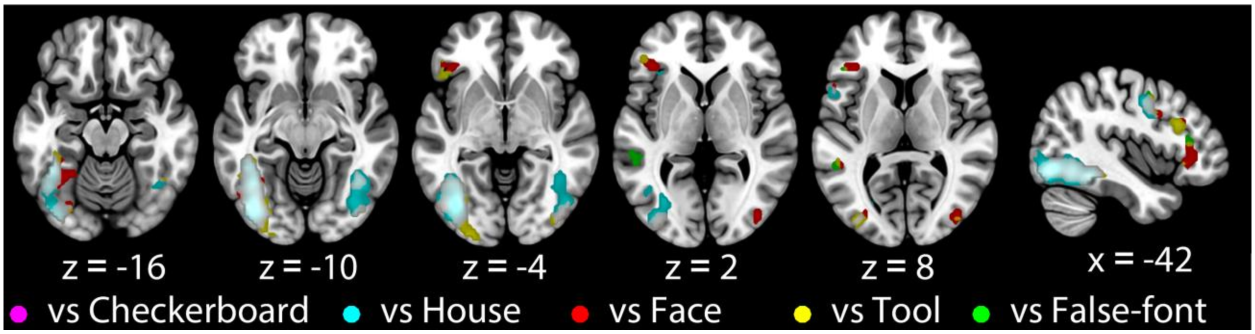
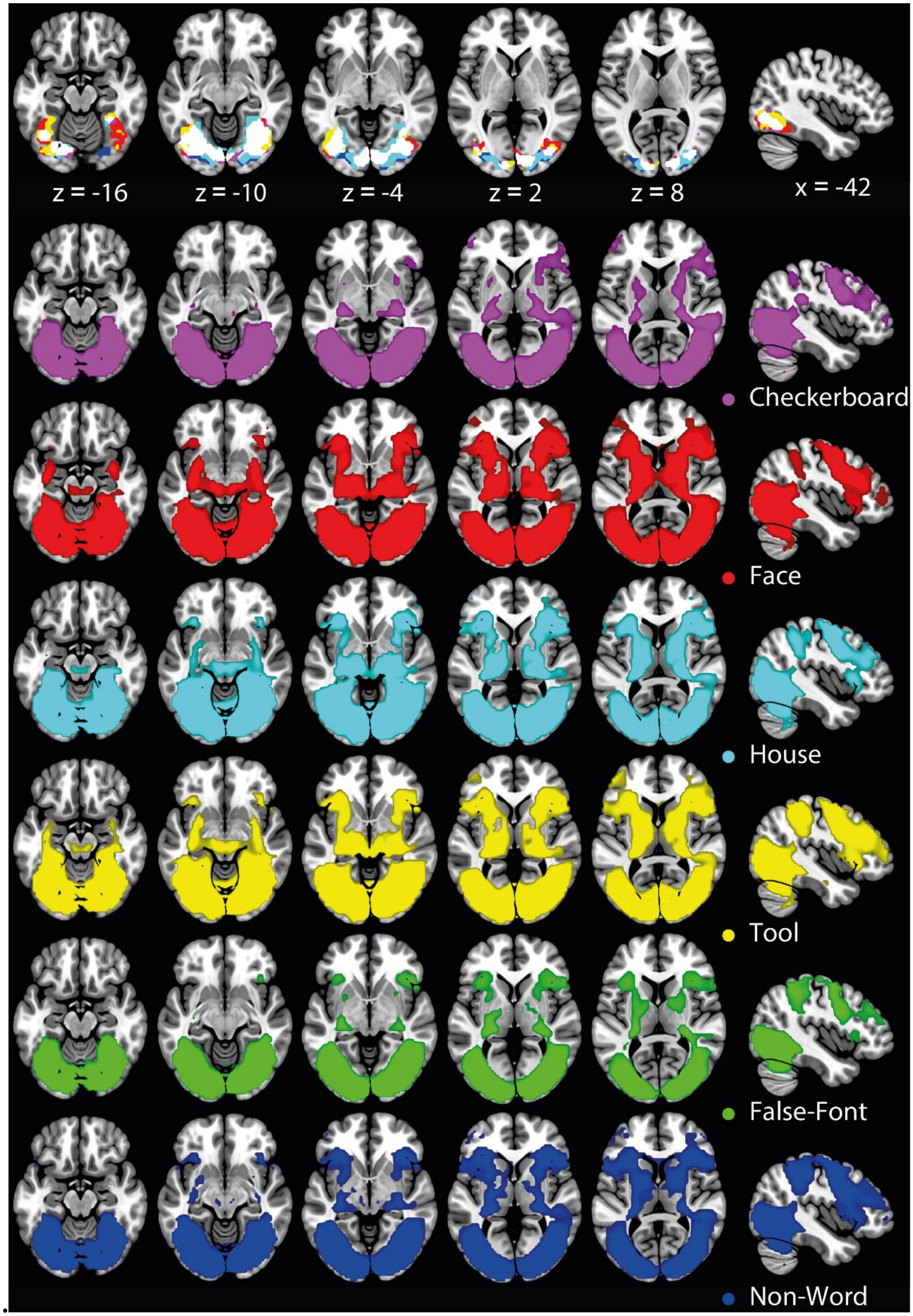


Fig. S1. Modulation of nonword responses by literacy. Areas showing significant (thresholded at $p<.001$, uncorrected for multiple comparisons) modulation by literacy of the contrast of Non-words vs other categories. Colours code the condition against which non-words are compared. Contrasts are projected onto the MNI152 single subject template brain, z and x coordinates indicate plane of section in MNI space.

Fig. S2



z = -16
z = -10
z = -4
z = 2
z = 8
x = -42
Checkerboard
Face
House
Tool
False-Font
Non-Word

Fig. S2. Activation maps for all conditions presented in the visual run. Top row shows convergence of the top 5% of most highly activated voxels for the contrast against baseline in bilateral occipital and ventral temporal areas. Each row shows the individual categories thresholded at a voxelwise $p<.001$ uncorrected for multiple comparisons.

Fig. S3.

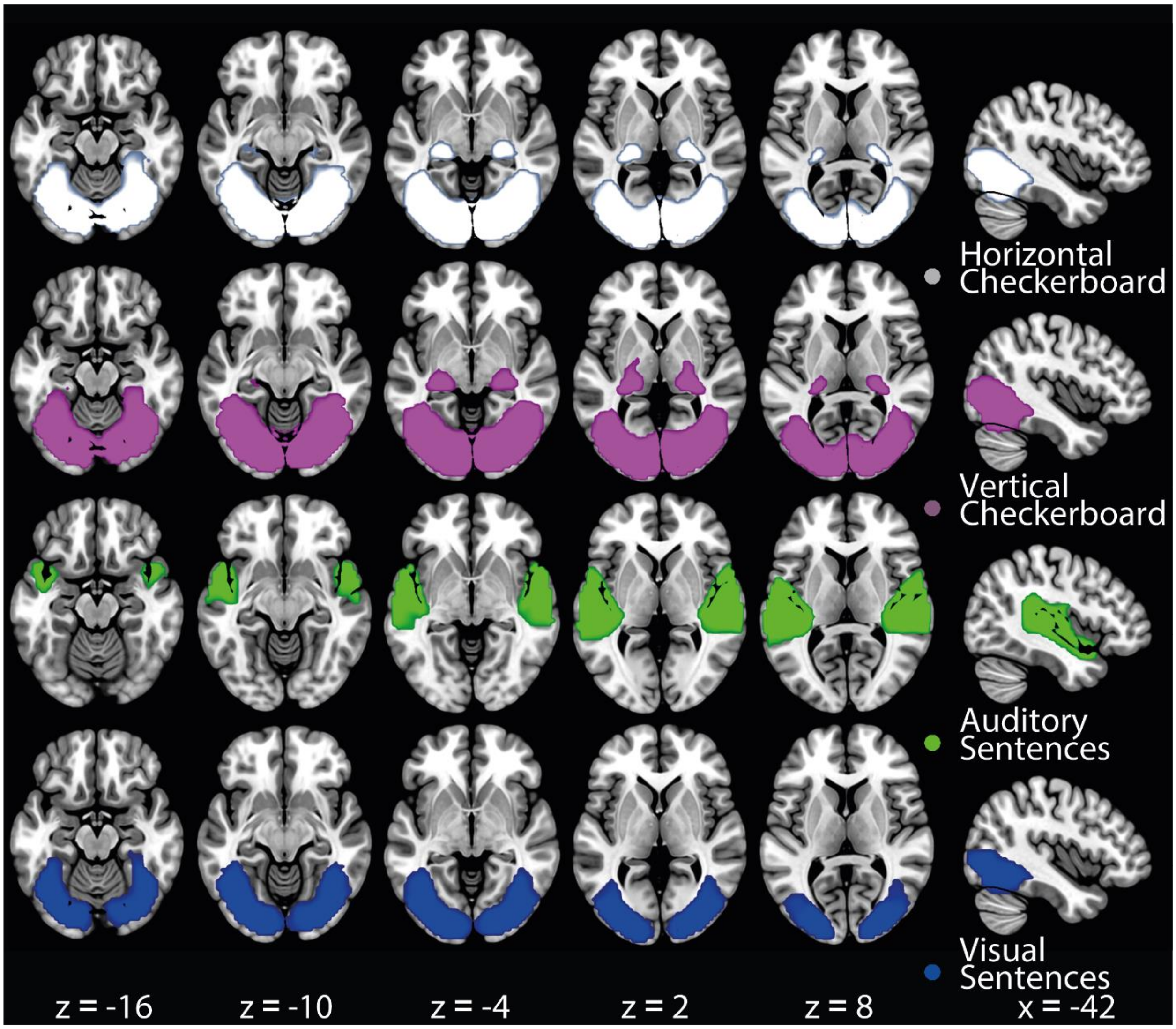


Fig. S3. Activation maps for all conditions presented in the localizer run. Each row shows the individual categories thresholded at a voxelwise $p<.001$ uncorrected for multiple comparisons.

Fig. S4.

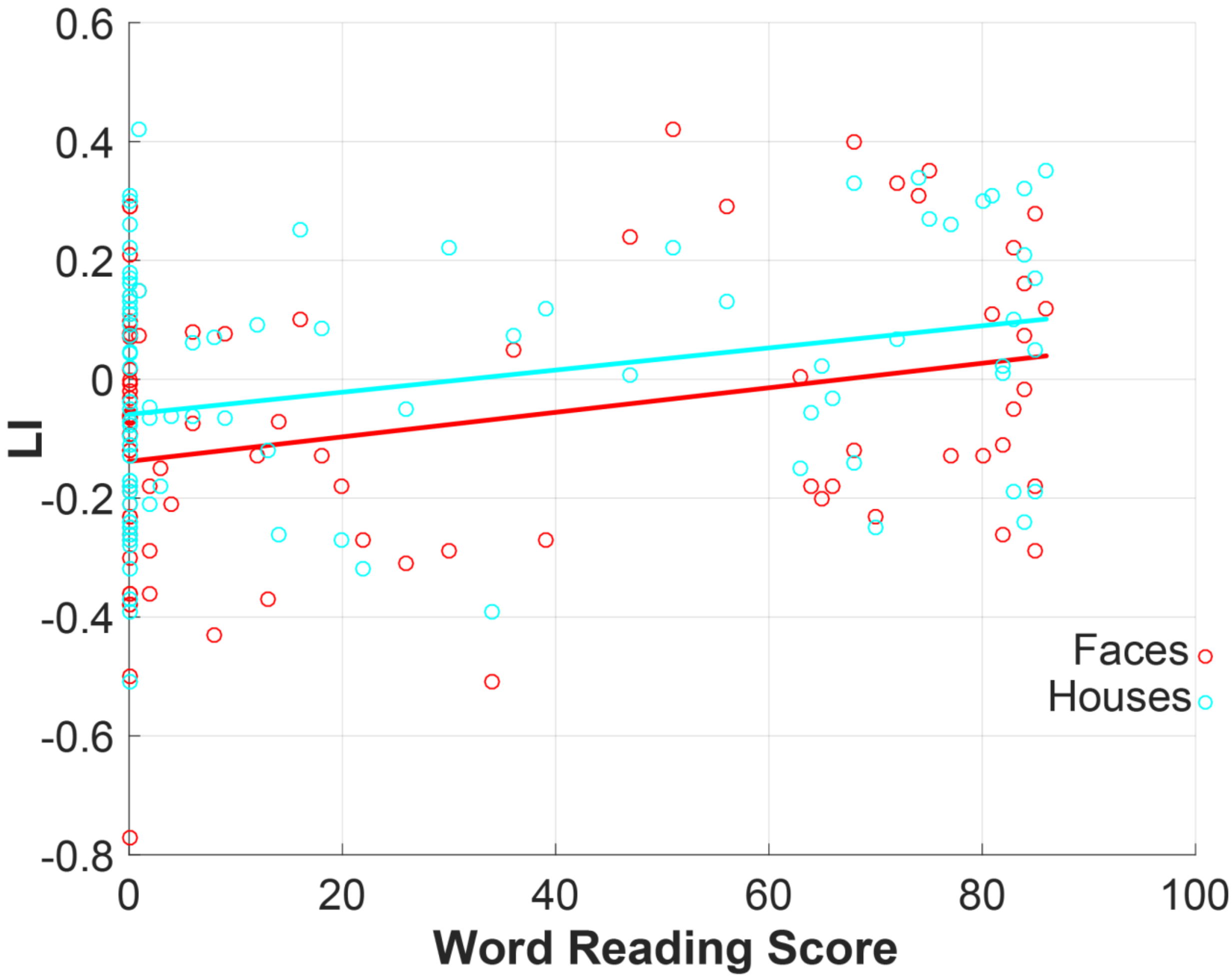
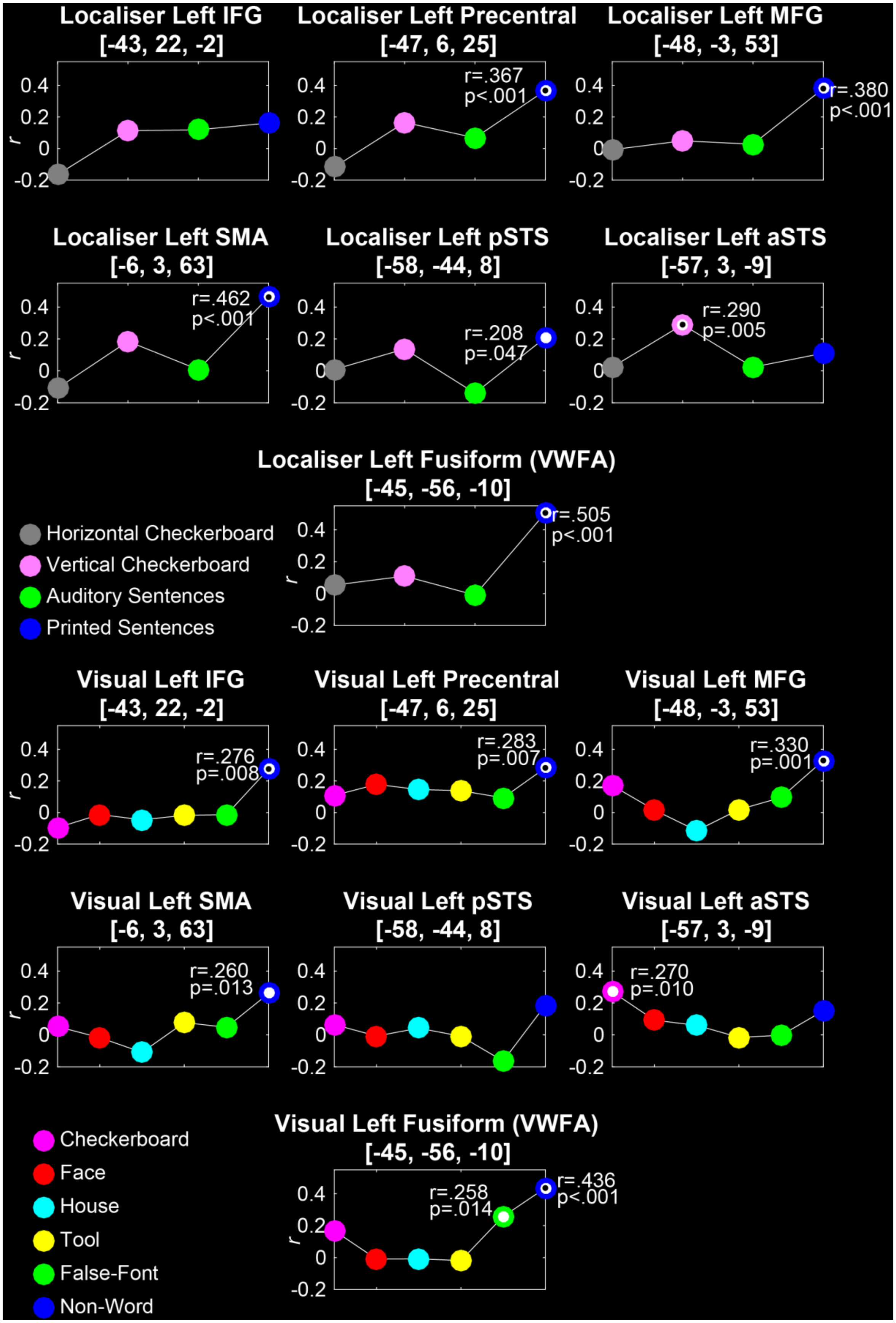


Fig. S4. Lateralization of responses to faces and houses. The relationship between lateralisation index (LI, negative values indicate rightward lateralisation, positive values indicate leftward lateralisation) for the responses in bilateral occipital lobes and bilateral fusiform gyrus to Faces (red circles) and Houses (cyan circles) and word-reading scores. Trendlines show fit of robust linear regression models, and indicate the positive relationship between reading ability and leftward lateralisation of response to each of these categories.

Fig. S5.



Localiser Left IFG [-43, 22, -2]
Localiser Left Precentral [-47, 6, 25]
r=.367 p<.001
Localiser Left MFG [-48, -3, 53]
r=.380 p<.001
Localiser Left SMA [-6, 3, 63]
r=.462 p<.001
Localiser Left pSTS [-58, -44, 8]
r=.208 p=.047
Localiser Left aSTS [-57, 3, -9]
r=.290 p=.005
Localiser Left Fusiform (VWFA) [-45, -56, -10]
r=.505 p<.001
Horizontal Checkerboard
Vertical Checkerboard
Auditory Sentences
Printed Sentences
Visual Left IFG [-43, 22, -2]
r=.276 p=.008
Visual Left Precentral [-47, 6, 25]
r=.283 p=.007
Visual Left MFG [-48, -3, 53]
r=.330 p=.001
Visual Left SMA [-6, 3, 63]
r=.260 p=.013
Visual Left pSTS [-58, -44, 8]
Visual Left aSTS [-57, 3, -9]
r=.270 p=.010
Visual Left Fusiform (VWFA) [-45, -56, -10]
r=.258 p=.014
r=.436 p<.001
Checkerboard
Face
House
Tool
False-Font
Non-Word
r
0.4
0.2
0
-0.2

Fig. S5. Correlations between literacy and brain response in selected language-related cortical areas. Seven a priori cortical areas were defined from previous studies (*7*, *18*). The graphs here indicate the correlation between literacy (as evaluated by word reading performance) and brain response to various stimuli at each of the loci indicated. Those correlations that reach a significant correlation are highlighted and the relevant correlation coefficient and two-tailed p value provided adjacent. Those that reach significance at $p<.05$ when applying a Bonferroni correction corrected for multiple comparisons within ROI (i.e. for four comparisons in the Localiser and six comparisons in the Visual runs) are indicated with a black dot on the white highlight.

Fig. S6.

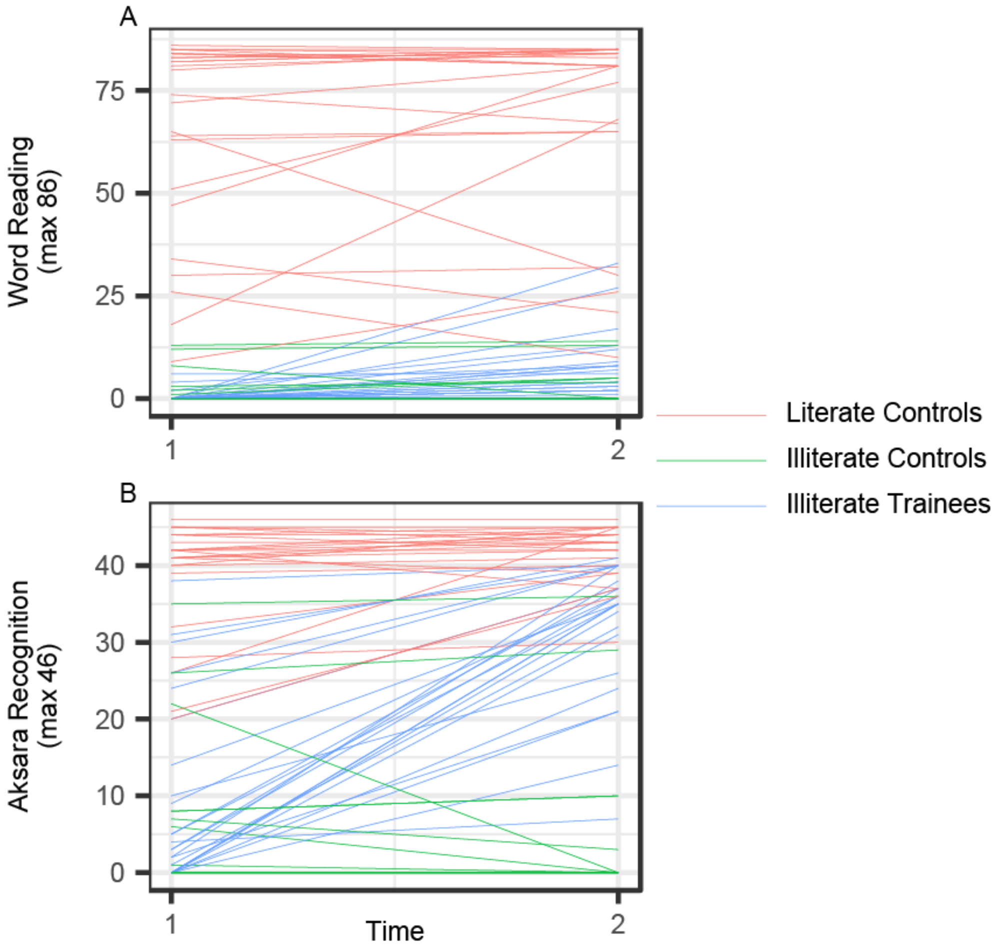


Fig. S6. Participants' literacy scores. A Participant performance at baseline and after 6 months for word reading. **B** Performance on Akshara recognition at baseline and after 6 months. Line colours indicate groups, as indicated in legend. Improvements in the trainees are apparent for both word reading and letter recognition, although the change in performance is heterogeneous, with some participants showing only minimal improvements on the tests used to evaluate literacy.

Table S1. Participant demographic information and behavioral performance at both time 1 and time 2.

	Trainees		**No Train**		**Literate**	
Time	*1*	*2*	*1*	*2*	*1*	*2*
N	29	22	24	12	38	26
Age (Range)	30.62 (23-39)	31.36 (24-39)	28.79 (19-40)	30.83 (22-40)	25.89 (18-40)	27.04 (18-40)
Sex [M:F]	2: 27	1: 21	8: 16	2: 10	25: 13	17: 9
Income (Range) [IRN/Month]	1775.86 (0-3000)	1795.45 (0-3000)	2250 (0-3000)	2500 (2000-3000)	2276.32 (0-9000)	2442.31 (0-9000)
Marital Status (Married:Unmarried:Widowed)	27:0:2	21:0:1	24:0:0	12:0:0	25:12:1	17:8:1
Handedness [R:L]	29:0	22:0	24:0	12:0	38:0	26:0
Number of Family Members	4.69 (2-8)	4.95 (2-8)	4.46 (2-7)	4.67 (2-7)	4.38 (2-8)	4.52 (2-8)
Number of Literate Family Members	2.36 (0-6)	2.71 (0-6)	2.64 (0-4)	2.89 (0-4)	2 (0-6)	1.89 (1-5)
Years of Schooling (Range)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	5.32 (0-12)	4.69 (0-11)
Word Reading Score (Range) [maximum 86]	0.48 (0-6)	7.59 (0-33)	2.5 (0-14)	3.42 (0-14)	59.21 (0-86)	68.44 (10-85)
Akshara recognition Score (Range) [maximum 46]	9.34 (0-38)	33.23 (14-41)	8.88 (0-35)	7.33 (0-36)	37.87 (17-46)	41.76 (30-46)
Raven's Matrices	13.97 (8-21)	12.85 (8-16)	13.63 (8-27)	13.17 (8-27)	17.58 (9-35)	17.65 (10-35)

Table S2. Significantly modulated brain responses to orthographic stimuli. Loci of peaks (separated by a minimum of 8mm) showing significant (cluster-level p<.05 FWE-corrected for multiple comparisons with a cluster-forming threshold of p<.001) modulation of activation across participants by literacy, when reading sentences and, below, non-words. Abbreviations: BA – Brodmann Area; Hem- Hemisphere, FWE – Familywise Error

Region Name [Brodmann Area]	Hem	MNI Co-ordinates (mm)	T-Score	z-Score	Voxel P(FWE)	Cluster P(FWE)	Cluster Size (Voxels)
		When Reading Sentences					
Occipital Fusiform Gyrus [BA19]	**L**	**-42, -73, -16**	**6.38**	**5.77**	**<.001**	**<.001**	**2262**
Fusiform Gyrus [BA37]	L	-42, -55, -10	6.07	5.54	<.001		
Superior Parietal Lobule [BA7]	L	-24, -52, 44	5.38	4.99	0.006		
Occipital Fusiform Gyrus [BA19]	R	39, -76, -7	5.19	4.84	0.012		
Middle Occipital Gyrus [BA19]	L	-30, -73, 20	5.18	4.83	0.012		
Lateral Occipital Gyrus	R	42, -85, -1	5.14	4.8	0.014		
Middle Occipital Gyrus [BA19]	L	-33, -76, -1	4.79	4.5	0.047		
Fusiform Gyrus [BA37]	L	-39, -43, -10	4.78	4.5	0.048		
Lingual Gyrus [BA18]	L	-21, -91, -16	4.76	4.48	0.051		
Middle Occipital Gyrus [BA18]	L	-36, -85, 5	4.46	4.23	0.13		
Cerebellum (lobule VI) [BA19]	R	27, -61, -25	4.42	4.19	0.148		
Cerebellum (lobule VI) [BA37]	R	33, -52, -25	4.41	4.18	0.154		
Cerebellum (Crus 1) [BA37]	L	-48, -61, -25	4.39	4.17	0.161		
Lateral Occipital Gyrus [BA18]	L	-24, -100, -1	4.33	4.11	0.19		
Calcarine Gyrus [BA18]	L	-12, -97, -10	4.3	4.09	0.207		
Fusiform Gyrus [BA37]	R	39, -52, -13	4.17	3.97	0.294		
Calcarine Gyrus [BA17]	--	0, -91, -10	4.11	3.93	0.333		
Lateral Occipital Gyrus [BA18]	L	-30, -94, 5	4.02	3.84	0.418		
Cerenbellum (lobule VI) [BA18]	R	12, -70, -22	3.96	3.79	0.472		
Calcarine Gyrus [BA18]	R	21, -100, 2	3.75	3.6	0.685		
Supplementary Motor Area [BA6]	**L**	**-6, 5, 56**	**5.57**	**5.14**	**0.003**	**<.001**	**191**
Supplementary Motor Area [BA32]	R	9, 14, 47	3.87	3.71	0.556		
Cerebellum (lobule VIII)	**R**	**30, -61, -49**	**5.31**	**4.94**	**0.008**	**<.001**	**104**
Cerebellum (lobule VIII)	R	18, -70, -43	4.42	4.19	0.147		
Precentral Gyrus [BA6]	**L**	**-51, 2, 47**	**5.09**	**4.75**	**0.017**	**<.001**	**361**
Precentral Gyrus [BA6]	L	-42, 2, 32	5	4.68	0.023		
Middle Frontal Gyrus [BA6]	L	-30, -4, 50	4.71	4.44	0.06		
Precentral Sulcus	L	-33, -7, 68	4.66	4.4	0.07		
Precentral Sulcus [BA6]	L	-45, -4, 56	4.37	4.15	0.171		
		When Reading Non-Words					
Precentral Gyrus [BA6]	**L**	**-51, 2, 47**	**5.84**	**5.36**	**0.001**	**<.001**	**540**
Precentral Gyrus [BA6]	L	-42, 2, 35	5.22	4.86	0.01		

Inferior Frontal Gyrus (p. triangularis) [BA45]	L	-48, 35, 17	5.17	4.82	0.012		
Precentral Gyrus [BA6]	L	-39, -4, 41	4.81	4.52	0.042		
Inferior Frontal Gyrus (p.opercularis) [BA44]	L	-54, 14, 11	4.62	4.36	0.077		
Precentral Gyrus [BA6]	L	-39, -4, 62	4.02	3.84	0.402		
Inferior Frontal Gyrus (p. triangularis) [BA45]	L	-45, 35, 5	3.94	3.77	0.481		
Inferior Frontal Gyrus (p. orbitalis) [BA47]	L	-36, 26, -4	3.64	3.5	0.774		
Inferior Frontal Gyrus (p. triangularis) [BA45]	L	-33, 23, 26	3.63	3.49	0.782		
Inferior Frontal Gyrus (p. triangularis) [BA45]	L	-30, 11, 26	3.57	3.44	0.826		
Anterior Insula	L	-27, 26, 8	3.54	3.41	0.853		
Fusiform Gyrus [BA19]	**L**	**-39, -79, -16**	**5.39**	**5**	**0.005**	**<.001**	**787**
Inferior Temporal Gyrus [BA37]	L	-42, -43, -13	5.24	4.88	0.009		
Middle Occipital Gyrus [BA18]	L	-24, -97, -1	5.15	4.81	0.013		
Fusiform Gyrus [BA37]	L	-39, -58, -13	4.88	4.58	0.034		
Middle Occipital Gyrus [BA18]	L	-36, -88, 5	4.6	4.34	0.084		
InferiorOccipital Lobe [BA37]	L	-51, -70, -7	3.68	3.54	0.731		
Inferior Parietal Lobule [BA40]	**L**	**-33, -49, 50**	**4.66**	**4.39**	**0.069**	**<.001**	**152**
Superior Parietal Lobule [BA7]	L	-24, -67, 59	4.04	3.86	0.385		
Superior Parietal Lobule [BA7]	L	-24, -64, 47	4.03	3.85	0.395		

Table S3. Correlation between literacy and brain response to visual categories in ventral temporal lobes. Statistics (Pearson's correlation coefficients and their associated p values) for the correlation between literacy and brain response to each condition in the visual runs (vs baseline) at the x co-ordinates displayed in Fig. 2, p values are provided uncorrected, † denotes values that are significant when applying an FDR correction for the 120 correlations tested in the table. X values refer to x co-ordinate in mm MNI space (y=-55 and z=-10 throughout).

X=	**-58**	**-54**	**-50**	**-46**	**-42**	**-38**	**-34**	**-30**	**-26**	**-22**
Checkerboard	r=.231, p=.028	r=.244, p=.020	r=.192, p=.068	r=.169, p=.110	r=.170, p=.107	r=.182, p=.085	r=.189, p=.072	r=.184, p=.080	r=.205, p=.051	r=.125, p=.237
Faces	r=.107, p=.311	r=.099, p=.349	r=.050, p=.640	r=-.010, p=.929	r=.012, p=.908	r=.045, p=.674	r=.030, p=.775	r=.006, p=.953	r=-.025, p=.814	r=-.028, p=.795
Houses	r=.049, p=.645	r=.070, p=.507	r=.061, p=.564	r=-.008, p=.941	r=-.033, p=.754	r=-.040, p=.710	r=.055, p=.603	r=.070, p=.507	r=.059, p=.579	r=-.017, p=.872
Tools	r=-.057, p=.590	r=-.005, p=.964	r=-.007, p=.945	r=-.018, p=.863	r=.009, p=.935	r=.045, p=.673	r=.037, p=.731	r=-.025, p=.811	r=-.055, p=.605	r=-.057, p=.592
False-fonts	r=-.067, p=.527	r=.020, p=.849	r=.118, p=.265	r=.258, p=.014	r=.322, p=.002†	r=.363, p<.001†	r=.280, p=.007	r=.226, p=.032	r=.182, p=.084	r=.016, p=.881
Non-words	r=.233, p=.027	r=.313, p=.003†	r=.352, p<.001†	r=.436, p<.001†	r=.470, p<.001†	r=.502, p<.001†	r=.416, p<.001†	r=.340, p<.001†	r=.275, p=.008	r=.087, p=.414
X=	**22**	**26**	**30**	**34**	**38**	**42**	**46**	**50**	**54**	**58**
Checkerboard	r=.116, p=.272	r=.072, p=.496	r=.083, p=.435	r=.010, p=.922	r=.005, p=.962	r=.049, p=.641	r=.216, p=.040	r=.217, p=.039	r=.194, p=.065	r=.114, p=.284
Faces	r=.037, p=.728	r=-.028, p=.790	r=-.053, p=.615	r=-.084, p=.427	r=-.071, p=.507	r=-.034, p=.750	r=.031, p=.773	r=.047, p=.658	r=.008, p=.943	r=-.033, p=.758
Houses	r=.044, p=.676	r=-.063, p=.554	r=-.127, p=.231	r=-.200, p=.058	r=-.208, p=.048	r=-.168, p=.112	r=-.002, p=.986	r=.019, p=.858	r=.010, p=.922	r=-.050, p=.638
Tools	r=-.059, p=.579	r=-.088, p=.406	r=-.076, p=.472	r=-.083, p=.434	r=-.089, p=.403	r=-.074, p=.489	r=.038, p=.721	r=.070, p=.513	r=.057, p=.592	r=.016, p=.882
False-fonts	r=.081, p=.447	r=.075, p=.478	r=.107, p=.313	r=.158, p=.134	r=.167, p=.113	r=.194, p=.065	r=.276, p=.008	r=.300, p=.004†	r=.239, p=.022	r=.027, p=.803
Non-words	r=.060, p=.571	r=.044, p=.680	r=.085, p=.422	r=.225, p=.032	r=.265, p=.011	r=.281, p=.007	r=.248, p=.018	r=.235, p=.025	r=.192, p=.068	r=.053, p=.620

Table S4. Loci of peaks showing an increased activation in response to sentences after training, for the subtraction "pretraining versus posttraining" in the participants who underwent literacy training. Table lists peaks separated by a minimum of 8mm, which are significant at the *uncorrected* voxelwise threshold of p<.001. These results are provided for illustration only and must be interpreted with due caution. Abbreviations: BA – Brodmann Area; Hem- Hemisphere, unc. – uncorrected for multiple comparisons

Region Name [Brodmann Area]	Hem	MNI Co-ordinates (mm) x, y, z	T-Score	z-Score	Voxel P(unc.)	Cluster P(unc.)	Cluster Size (Voxels)
Middle Occipital Cortex [BA19]	**L**	**-36, -73, 32**	**4.87**	**3.94**	**<0.001**	**0.051**	**47**
Middle Frontal Gyrus [BA8]	**L**	**-30, 17, 59**	**4.66**	**3.82**	**<0.001**	**0.014**	**81**
Middle Frontal Gyrus [BA6]	L	-36, 5, 62	4.38	3.65	<0.001		
Precentral Gyrus [BA6]	L	-42, -4, 50	4.02	3.42	<0.001		
Middle Frontal Gyrus [BA9]	L	-36, 11, 50	3.88	3.33	<0.001		
Fusiform Gyrus [BA37]	**L**	**-36, -49, -10**	**4.65**	**3.81**	**<0.001**	**0.249**	**15**
Fusiform Gyrus [BA37]	L	-39, -52, -19	3.87	3.33	<0.001		
Middle Occipital Cortex [BA19]	**R**	**33, -79, 17**	**4.48**	**3.71**	**<0.001**	**0.053**	**46**
Cerebellum Vermis VII	**R**	**6, -70, -28**	**4.41**	**3.67**	**<0.001**	**0.028**	**62**
Cerebellum Lobule VI	R	-6, -70, -22	4.02	3.42	<0.001		
Middle Temporal Gyrus [BA37]	**R**	**42, -61, 17**	**4.31**	**3.61**	**<0.001**	**0.176**	**21**
Fusiform Gyrus [BA19]	**L**	**-27, -79, -10**	**4.3**	**3.6**	**<0.001**	**0.066**	**41**
Cerebellum Lobule VI	**R**	**30, -64, -28**	**4.26**	**3.57**	**<0.001**	**0.083**	**36**
Cerebellum Crus I	R	42, -67, -28	3.88	3.33	<0.001		
Occipitotemporal Cortex [BA37]	**R**	**42, -49, -4**	**4.21**	**3.55**	**<0.001**	**0.018**	**74**
Fusiform Gyrus [BA37]	R	39, -55, -13	4.03	3.43	<0.001		
[BA20]	R	48, -40, -10	3.97	3.39	<0.001		
Inferior Temporal Gyrus [BA37]	R	42, -64, -10	3.55	3.1	<0.001		
Thalamus	**R**	**21, -25, 2**	**4.17**	**3.52**	**<0.001**	**0.249**	**15**
Precentral Gyrus [BA6]	**R**	**51, -1, 50**	**4.04**	**3.44**	**<0.001**	**0.302**	**12**
Fusiform Gyrus [BA19]	**R**	**30, -79, -7**	**3.85**	**3.31**	**<0.001**	**0.166**	**22**

Table S5. Loci of peaks showing an increase in activation in response to sentences after training, the magnitude of which is significantly correlated with the improvement in reading score in the participants who underwent literacy training. Table lists peaks separated by a minimum of 8mm, which are significant at a threshold of p<.05, FWE corrected for multiple comparisons at the cluster level (cluster forming threshold p<.001 uncorrected). Abbreviations: BA – Brodmann Area; Hem- Hemisphere, FWE – Familywise Error

Region Name [Brodmann Area]	Hem	MNI Co-ordinates (mm) x, y, z	T-Score	z-Score	Voxel P(FWE)	Cluster P(FWE)	Cluster Size (Voxels)
Superior Occipital Cortex [BA18]	**R**	**18, -91, 32**	**8.18**	**5.36**	**0.002**	**0**	**276**
Cuneus [BA17]	R	12, -97, 14	6.33	4.64	0.047		
Superior Occipital Cortex [BA18]	L	-15, -88, 20	6.27	4.61	0.052		
Cuneus	L	3, -91, 26	4.62	3.77	0.606		
Cuneus [BA18]	L	-6, -94, 26	4.56	3.73	0.645		
Superior Occipital Cortex [BA19]	R	24, -73, 20	4.45	3.67	0.713		
Precuneus [BA19]	L	27, -64, 23	4.22	3.53	0.841		
Middle Occipital Cortex [BA39]	**L**	**-39, -76, 17**	**7.44**	**5.09**	**0.008**	**0.013**	**126**
Middle Occipital Cortex	L	-36, -91, 14	4.89	3.92	0.445		
Middle Occipital Cortex [BA19]	L	-30, -85, 35	4.28	3.57	0.808		
Left Inferior Frontal Gyrus (pars triangularis) [BA47]	**L**	**-30, 38, -1**	**6.32**	**4.63**	**0.048**	**0.006**	**153**
Left Inferior Frontal Gyrus (pars triangularis) [BA45]	L	-45, 20, 5	4.87	3.91	0.452		
Left Inferior Frontal Gyrus (pars opercularis)	L	-45, 17, 14	3.92	3.34	0.951		
Left Inferior Frontal Gyrus (pars triangularis) [BA45]	L	-39, 32, 8	3.86	3.3	0.964		