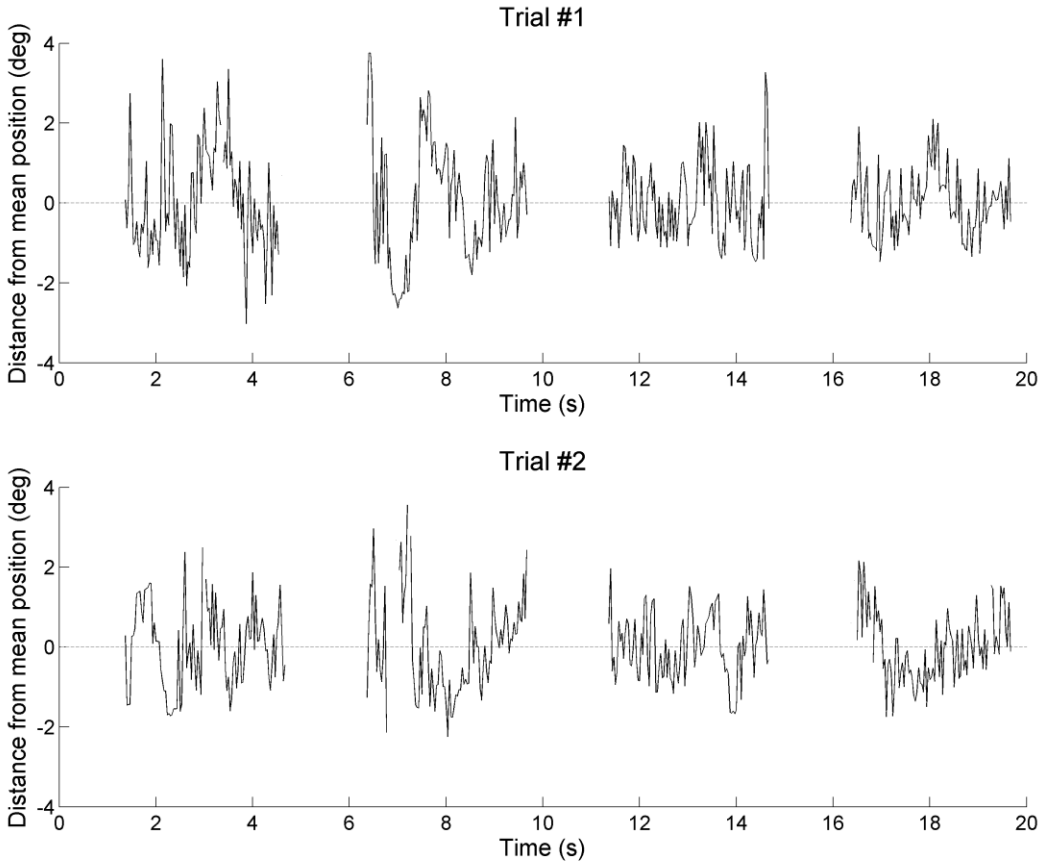
Supplemental Data

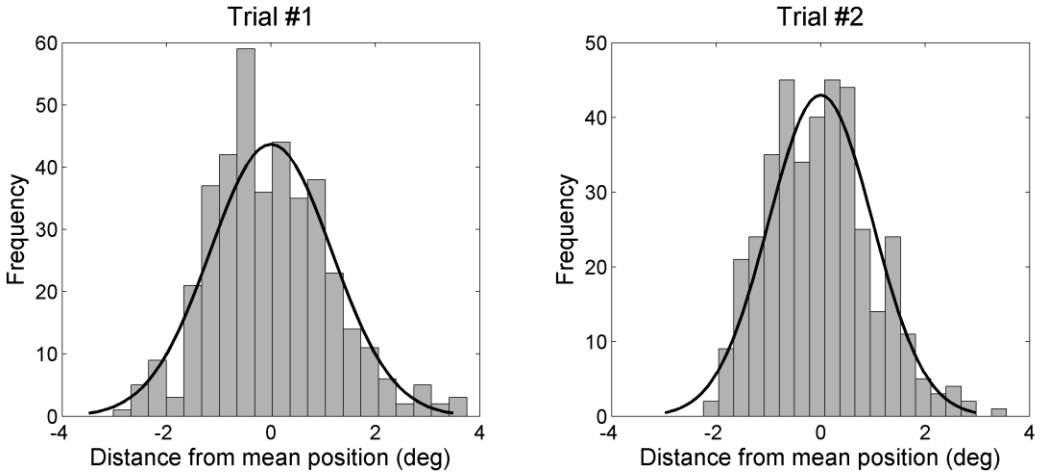
Fixation stability measurements

Fixation stability was measured with a video-based method. Images (video frames) of S's left eye were recorded at 30 Hz using a Logitech QuickCam® Pro 5000. The resolution of each recorded video frame was 640 × 480 pixels. The pupil was identified by thresholding each video frame. The positions of the pupil across different video frames were tracked by the center of an ellipse fitted to the pupil. During each 20-second trial, S looked back and forth at two horizontally separated dots, each for 5 seconds. The dots were 21.2° apart, produced by two LEDs (diameter = ~0.5°). For each 5-second period, we calculated the Euclidean distance between the gaze position at each time point and the mean gaze position. Time points corresponding to eye movements between the two fixation locations were excluded from each 5-second period, leaving 3.33 seconds in each segment. S performed this fixation task twice. Supplementary Figure S1 shows the distance from mean position as a function of time for the four segments in each 20-second trial. Supplementary Figure S2 shows the distributions of the distance from mean position for the two trials. The standard deviations of the distributions in the trials #1 and #2 were 1.1633° and 0.9922° respectively. The average of the standard deviations in the two trials was 1.08°. Thus, S's fixation position was within 1.08° for 68% of the time. While this value is larger than typical values for normally sighted people, it makes clear that S does not suffer from nystagmus and that his fixation is adequate for the purposes of our study.

Supplementary Figure S1. S's fixation stability. Distance from mean fixation position in deg was plotted against time in second. Upper and lower panels show the data from trials #1 and #2 respectively. Each segment was 3.33 seconds.



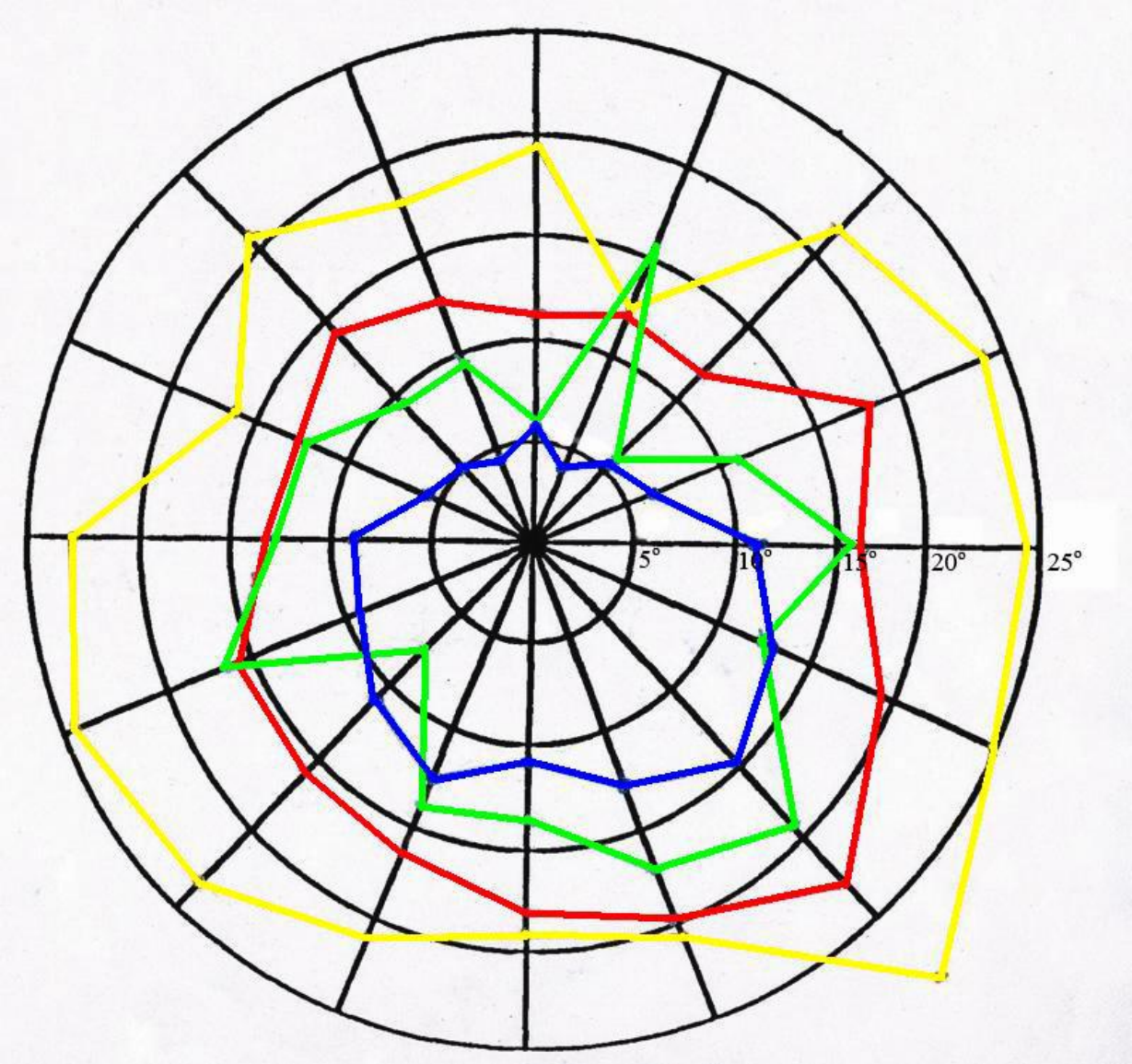
Supplementary Figure S2. Histograms summarizing S's fixation stability. Data points for distance from mean fixation position in each trial were grouped into 20 bins. The frequency count in each bin was plotted as a function of distance from mean position. The histogram was fitted with a normal distribution as indicated by the black curve. Left and right panels show the data from trials #1 and #2 respectively.



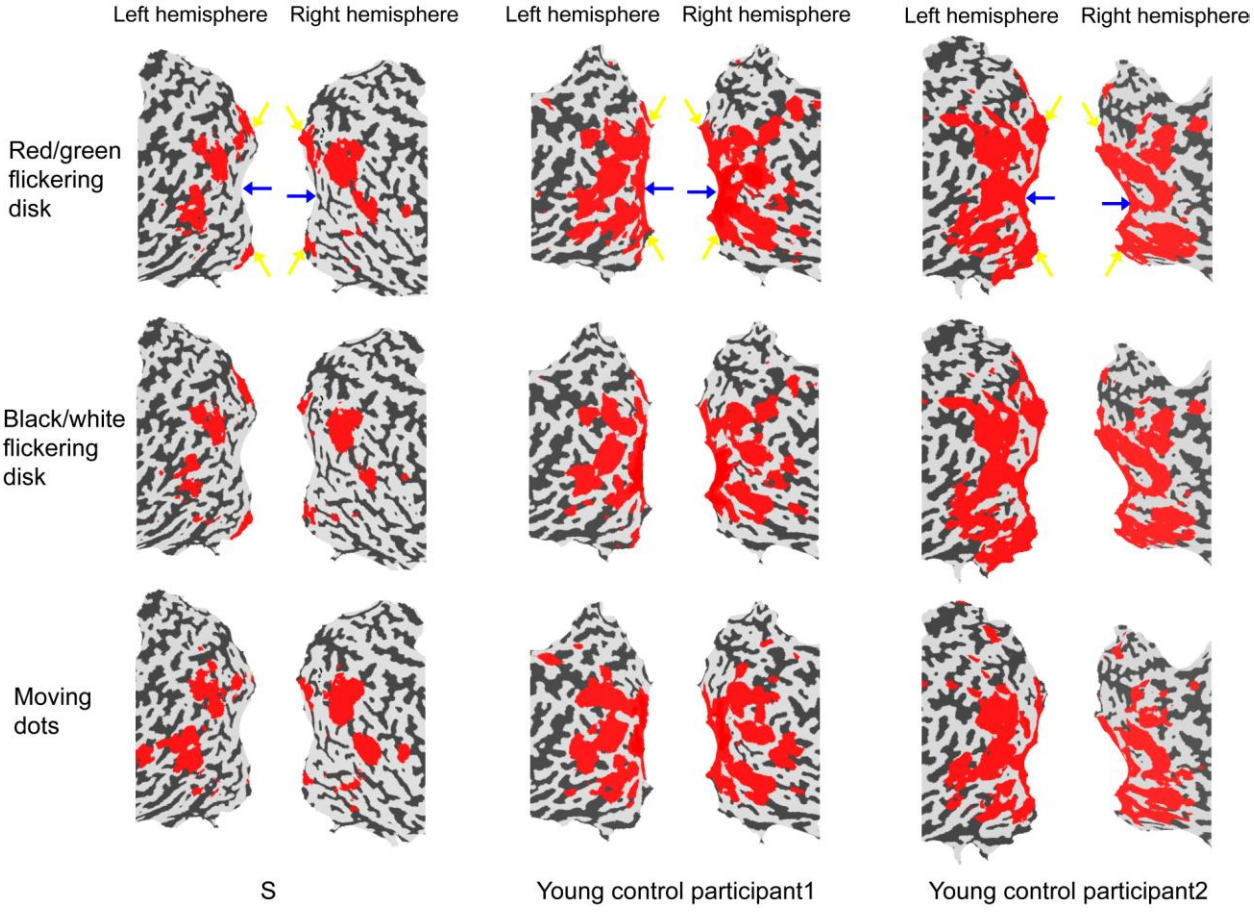
Tangent field measurements

The central visual field of S's right eye was mapped using a large white target (40 mm, 2.29° of visual angle) on a tangent screen at 1 m while S fixated on a large white spot (43mm, 2.5° of visual angle). S was tested with or without glasses (note that S's fMRI testing was carried out without glasses). In separate measurements, isopters were measured with the target moving from the periphery inward and from fixation outward. For the periphery-inward measurement, the target was brought toward the fixation mark along a radial line until S said "yes, I see it". For the fovea-outward measurement, the target was brought along a radial line from the fixation mark outward until S said "No, I don't see it." So the "outward" isopter defined the region around fixation where S could see the target. Supplementary Figure S3 shows the testing result. Blue contour is for the inward and with glasses condition, red contour for the outward and with glasses condition, green contour for the inward and without glasses condition, and yellow contour for the outward and without glasses condition. The average diameter (twice the average of the radial measures) of the field was 32°, close to the size of the display used in the experiments. (S's field size would almost certainly be larger for a larger target.) These field measurements confirm that S's central visual field contains no large scotoma.

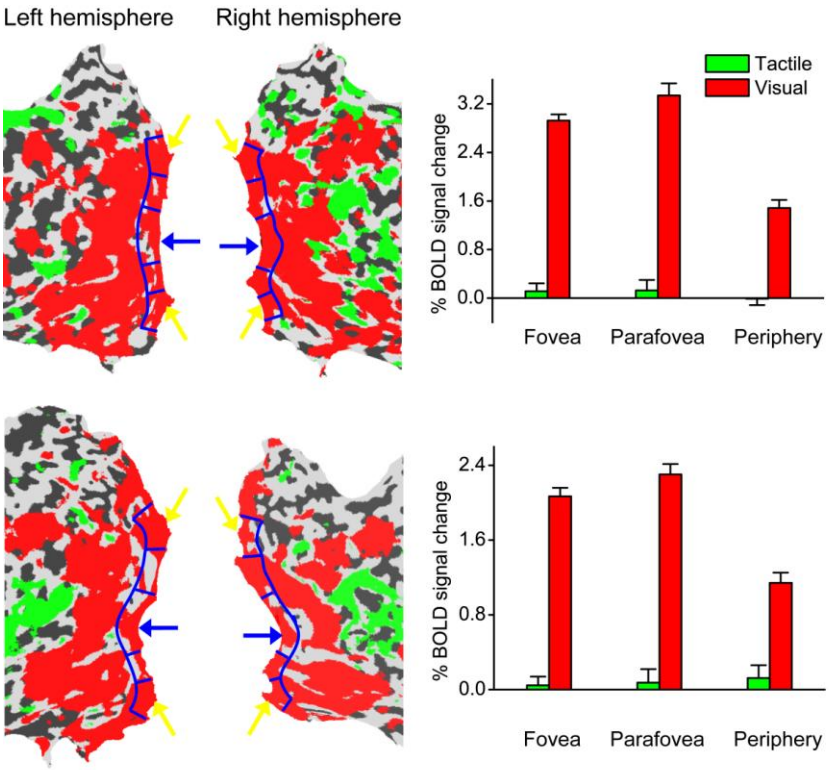
Supplementary Figure S3. Result of tangent field testing with S.



Supplementary Figure S4. fMRI activation maps by visual stimuli in S and two young control participants. Statistical significance maps (thresholded at corrected $p < 0.01$) are shown on the flattened surface reconstruction of the posterior part of participants' brains. Red regions were activated by visually presented red/green flickering disks (top row), black/white flickering disks (middle row) and moving dots (bottom row) contrasting with blank intervals. Participants' foveal and peripheral representations in V1 are indicated by blue and yellow arrows respectively.



Supplementary Figure S5. fMRI activation maps by visual letter string and tactile dot (Braille) stimuli in two young control participants (upper row for the first participant and lower row for the second participant). Statistical significance maps (thresholded at corrected $p < 0.01$) are shown on the flattened surface reconstruction of the posterior part of participants' brains. Left: Visual letter string and tactile dot conditions were contrasted with each other. Red regions showed higher response to visual letter strings than to tactile dots, and green regions showed the opposite. Participants' foveal and peripheral representations in V1 are indicated by blue and yellow arrows respectively. Right: BOLD signals evoked by visual letter strings and tactile dots relative to blank intervals in three V1 subregions (fovea, parafovea and periphery), which are delineated by blue curves on the flattened surfaces. Error bars denote 1 standard error of mean across scans.



Supplemental Experimental Procedures

Participants

Five adults, including S, participated in this study. Two of them are gender- and age-matched control participants (56 and 59 years old, both are males) for S, and the other two are young control participants (between 25 and 30 years old, one male and one female). All control participants are right-handed, reported normal or corrected-to-normal vision, and had no known neurological or visual disorders. All participants gave written, informed consent in accordance with procedures and protocols approved by the Institutional Review Board of the University of Minnesota.

Stimuli and design

Visual stimuli were generated using MATLAB 5.2.1 (MathWorks, Massachusetts, USA) with Psychophysics Toolbox extensions [S1, S2] on a Power Mac G4 computer (Apple, California, USA). The stimuli used in this study are described below with their corresponding fMRI scan protocol.

1. ***Visual symbol/pattern categorization scan***. Uppercase letters and digits in Courier font, and simple geometric shapes were used in the visual symbol/pattern categorization scans. These 12° high yellow-on-blue stimuli were presented at the center of the display. During the stimulus blocks, each stimulus was displayed for 1.5 s every 2 s leaving a 0.5 s blank between stimuli. The participant indicated the categories to which the stimulus belonged by pressing one of two buttons. The categories were vowel or consonant for letters, even or odd for digits, and symmetric or asymmetric for shapes. The sequence of stimulus presentation was: letters, shapes, digits, and then repeated in reversed order with a

fixation-only block following each stimulus block. Both stimulus and fixation blocks were 20 s long resulting in a scan that lasted for 240 s.

2. ***Visual flickering disk scan***. The flickering disks were 26° in diameter, formed by four 90 deg wedges. The wedges were sub-divided at the half-radius point so that there was a total of eight checks. The checks were either black and white or equiluminant red and green. The disks counter-phase flickered at 8 Hz on a gray background either between black and white or between red and green. One cycle of stimulation had four blocks in this order: black/white, blank, red/green, blank. Both stimulus and blank blocks were 20 s and there were three cycles, which resulted in a 240 s scan.
3. ***Visual motion scan***. The stimulus used in the visual motion scan was comprised of 28 white dots of 1.5° diameter randomly distributed on a black background within a circular field of 20° diameter. A 2° yellow central fixation cross was used. During the moving-dot blocks, the dots moved radially to or from the center at 10° per second. The direction of motion alternated every second. Six cycles of moving- and stationary-dot blocks were used in each motion scan. All blocks were 20 s, which resulted in a 240 s scan.
4. ***Visual and Braille lexical decision scan***. The stimuli were letter strings of three characters, presented as Braille for touch or as print for vision. Uncontracted Braille letter strings were embossed on a 7 cm × 8 cm card. Twenty letter strings were arranged in four columns on each card with column separation of one empty Braille space. Each Braille letter extended no more than 6 mm × 3.8 mm. The card was affixed to a plastic board that sat on the participant's lap. S read the stimuli with self pacing at an approximate rate of one string every 4 s. Visual letter strings with 8° high yellow-on-blue lowercase Courier characters were presented for 3 s every 4 s, leaving a 1 s blank between visual

presentations. The beginning and end of the stimulus block were signaled by two flashes and one flash respectively. The flash was red for the visual (V) block and green for the Braille (B) block. Each stimulus block was followed by a rest block with a blank screen. The sequence of stimulation was: V, B, B, V, B, V, V, B. The participant indicated whether the letter string, presented either in Braille or print, was a word or not by pressing one of two buttons. The normally-sighted control participants who could not read Braille were asked to feel the Braille symbols and to count the dots, instead of performing the Braille lexical decision task. Each block was 20 s long resulting in a scan that lasted for 320 s.

5. ***Visual and tactile shape categorization scan***. The stimuli were simple geometric shapes (e.g., triangle, rectangle, trapezoid, etc.), presented visually or tactually. Participants indicated the categories (left-right symmetric or asymmetric) to which the shape belonged by pressing one of two buttons. For the tactile stimuli, twenty geometric shapes were embossed on a card, and were arranged in four rows on each card. Each tactile shape extended at least 12 mm × 12 mm. The card was affixed to a plastic board that sat on the participant's lap. In the tactile (T) blocks, participants followed auditory cues (“one”, “two”, etc.) and categorized the stimuli at a rate of one shape every 4 s, five stimuli for each block. The visual stimuli were 12° high yellow-on-blue geometric shapes presented at the center of the display. Each stimulus was presented for 4 s and each visual (V) block consisted of five such stimuli. The sequence of stimulation was: V, T, T, V, T, V, V, T. Each stimulus block was followed by a 20 s blank block resulting in a 320 s scan. An auditory instruction (“visual” or “tactile”) was presented as a reminder immediately before a stimulus block. In order to balance auditory stimulation between

different types of blocks, the same auditory cues (“one”, “two”, etc.) were also presented to the participants in the visual and the blank blocks.

6. ***Visual word and visual imagery scan***. There were four 20 s visual word blocks and four 20 s visual imagery blocks, each of which was followed by a 20 s blank block. Each scan lasted 320 s and the order of these two kinds of blocks was counterbalanced within a scan. Each visual word block consisted of five three-letter words, each of which was presented at the center of the display for 4 s. The dimension of the visual words extended no more than 16° × 7°. The letters were rendered with a combination of red/green color and lower/upper case on a black background. During the visual presentation of a word, its pronunciation was delivered to the participants and they were asked to judge its color (red/green) or case (lower/upper), depending on the auditory instruction presented immediately before that block. In the visual imagery block, the pronunciations of five three-letter words were delivered to the participants successively and the participants were asked to imagine these words in a color (red/green) or case (lower/upper) specified by the auditory instruction presented immediately before that block. In order to balance auditory stimulation between stimulus blocks and blank blocks, “rest” was pronounced five times to the participants in each blank block.

All visual tasks were performed with the participants' right eye only, with their left eye patched. This is because S relies exclusively on his right eye for visual pattern recognition and reading. The Braille and tactile tasks were performed with the participants' left index finger, S's preferred Braille reading finger. All normally-sighted control participants wore diffuser goggles which blurred their measured visual acuity to approximately 20/1000, simulating S's retinal image quality.

MRI data acquisition

In the scanner, the visual stimuli were back-projected via a video projector (60 Hz) onto a translucent screen placed inside the scanner bore. Participants viewed the stimuli through a mirror located above their eyes. Functional MRI data were collected using a 3T Siemens Trio scanner with a high-resolution eight-channel head array coil. BOLD signals were measured with an echo-planar imaging (EPI) sequence (TE: 30ms, TR: 2000 ms, FOV: 22 × 22 cm^2, matrix: 64 × 64, flip angle: 75, slice thickness: 4 mm, number of slices: 20, slice orientation: axial), except in the first session for S (TE: 30ms, TR: 2000 ms, FOV: 22 × 22 cm^2, matrix: 64 × 64, flip angle: 60, slice thickness: 4 mm, number of slices: 16, slice orientation: axial). The bottom slice was positioned at the bottom of the temporal lobes. T2- weighted structural images at the same slice locations were collected for coregistration. A high-resolution T1-weighted 3D structural data set (3D MPRAGE; 1 × 1 × 1 mm^3 resolution) was collected in the same session before the functional runs.

S participated in four sessions: the first session consisted of three visual symbol/pattern categorization scans, two visual flickering disk scans and two visual motion scans; the second three visual and Braille lexical decision scans; the third four visual and tactile shape categorization scans and two visual word and visual imagery scans; the fourth two visual word and visual imagery scans. Two young controls participated in a session consisting of three visual and Braille lexical decision scans, two visual flickering disk scans and two visual motion scans. Two age-matched controls participated in a session consisting of three visual and tactile shape categorization scans.

MRI data processing and analysis

The anatomical volume for each participant in the first session was transformed into a

Talairach brain space [S3] that was common for all participants, then inflated and flattened (after a cut along the calcarine sulcus) using BrainVoyager 2000. Functional volumes in all the sessions for each participant were preprocessed which included 3D motion correction using SPM2, linear trend removal, and high-pass (0.015 Hz) [S4] filtering using BrainVoyager 2000. The images were then aligned to the anatomical volume in the first session and transformed into Talairach space. The first 20 s of BOLD signals were discarded to minimize transient magnetic-saturation effects.

Cortical activation maps by contrasting different stimulus conditions or contrasting a stimulus condition with blank intervals were generated using a general linear model (GLM) in which the regressors were boxcar waveforms modeling each stimulus condition, convolved with a canonical hemodynamic response function (δ=2.5, τ=1.25) [S5]. Regions of interest (ROIs) in S's V1 were defined as three contiguous areas along the calcarine sulcus, including its lower and upper banks. These three areas were of roughly the same size and corresponded to S's fovea, parafovea and periphery. To calculate the percentage signal change, the time course of BOLD signal intensity was first extracted by averaging the data from all the voxels within a predefined ROI, and then normalized by the average signal between 16 and 20 s in all blank intervals. The BOLD signal evoked by a stimulus condition was the average percentage signal change between 8 and 20 s in that stimulus blocks, as the signal usually took 6-7 s to rise to the full magnitude in each block. The BOLD signals were collapsed across left and right hemispheres. Standard errors of mean were calculated across all blocks with the same type of stimulus.

Supplemental References

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S4. Smith, A.M., Lewis, B.K., Ruttimann, U.E., Ye, F.Q., Sinnwell, T.M., Yang, Y., Duyn, J.H., and Frank, J.A. (1999). Investigation of low frequency drift in fMRI signal. NeuroImage 9, 526-533.

S5. Boynton, G.M., Engel, S.A., Glover, G.H., and Heeger, D.J. (1996). Linear systems analysis of functional magnetic resonance imaging in human V1. J. Neurosci. 16, 4207-4221.