Data were collected from four male Rhesus monkeys (*Macaca mulatta*) weighing between 10 and 12 kg: two for the SC recordings (monkeys I and U) and two for the V1 recordings (monkeys D and Y). For the SC recordings, surgical procedures and extracellular recording techniques have been detailed previously (45). For V1 recordings, one animal (monkey D) had a recording chamber implanted over V1, centered on the midline to allow access to both left and right lower visual field representations using single microelectrodes. In the second animal (monkey Y), a 96-channel microelectrode array (Blackrock Microsystems) was chronically implanted on the surface of the right V1 using surgical procedures outlined by Blackrock Microsystems (46). All animal care and experimental procedures were approved by the Queen’s University Animal Care Committee in accordance with the guidelines of the Canadian Council on Animal Care.

Stimuli and Equipment. Visual stimuli were presented on a high-definition LCD video monitor (Sony Bravia 55 inch; model KDL-46XBR6) at a screen resolution of 1,920 × 1,080 pixels (60-Hz noninterlaced, 16-bit color depth). Viewing distance was 70 cm, resulting in a viewing angle of 82° horizontally and 52° vertically. The viewing area that extended beyond the monitor was blackened using black nonreflective cloth.

The main stimuli consisted of a radial arrangement of equally spaced color bars (210 items), with the diameter of the entire display spanning 40° to 45° visual angle (Fig. 1 C and D). The items were horizontally or vertically oriented (typically 0.4° × 1.2° but modified slightly depending on RF size of V1 neurons) and were red or green derived from the red-green cardinal axis in Derrington-Krauskopf-Lennie (DKL) color space (47), with ~40° luminance contrast relative to the neutral gray background (65 cd/m²). The main condition consisted of a stimulus array with a single oddball that was always the opposite color and orientation as the remaining items [e.g., red horizontal against green vertical (depicted in Fig. 1 C and D), red vertical against green horizontal, green horizontal against red vertical, green vertical against red horizontal].

The oddball could appear IN or OPP the RF. This was compared with a single-item control condition, in which a single red or green, horizontal or vertical, stimulus appeared IN or OPP the RF (Fig. 1 E and F). All experimental conditions were interleaved.

The tasks were controlled by a Dell 8100 computer running a UNIX-based real-time data control system [real-time experimentation system (REX) 7.6] (48), which communicated with a second computer running in-house graphics software (written in C++) for presentation of stimuli. Stimulus timing was controlled using a photodiode placed at the left lower corner of the monitor and hidden by nonreflective tape. The photodiode measured the onset of a stimulus (20 × 20 pixels) that pulsed for one frame simultaneously with the onset of the main stimuli (i.e., the photodiode stimulus turned white for one frame and then returned to black). The REX was synchronized to the timing of the photodiode pulse by holding the current state until the pulse was detected.

Eye position was monitored using a 1,000-Hz video-based eye tracker (Eyelink 1000; SR Research). Saccades were detected based on a velocity (eye position > 50%/s) and amplitude (>1°) criteria and confirmed offline. Saccade end was defined as the point in time when the velocity of a detected saccade first fell below the saccade threshold defined above and was successfully inside the ~3° × 3° computer-controlled (imaginary) target window required for receiving a reward (only rewarded trials were analyzed). The data were recorded in a third computer running a multichannel data acquisition system (Plexon Inc.). Eye position, event data, and spike times were digitized at 1 kHz.

Procedure. Monkeys were seated with the head restrained in a primate chair (Crist Instruments) ~70 cm from the LCD video monitor. For SC recordings, single glass-insulated tungsten microelectrodes (2.0 MΩ; Alpha Omega) were lowered into the SC through a stainless steel guide tube. For V1 recordings in one animal (monkey D), we used more durable tungsten microelectrodes (250-μm shank diameter; 1.0 MΩ; FHC) that were able to pierce directly through the dura stabilized by a guide tube that was positioned against the dura. V1 recordings in the second animal (monkey Y) were obtained from a 96-channel chronically implanted microelectrode array (impedance range = 0.08–0.35 MΩ; Blackrock Microsystems). The animals viewed a dynamic video, which provided rich visual stimulation that facilitated the localization of the visually responsive dorsal SC surface or the uppermost layers in V1.

When a neuron was isolated, its visual RF was mapped using a rapid visual stimulation procedure described previously (21). Briefly, for SC neurons, single stimuli (white spot against a black background) were successively flashed (150-ms flashes with 150-ms interflash intervals) across the visual field, while the animal held fixation on a central fixation stimulus. For V1 neurons, with RFs that are significantly smaller than in SC (36, 37), the visual stimulation procedure was localized within a ~5° × 5° grid positioned over the approximate location of the neuron’s RF. The exact size and position of the stimulus grid could be manipulated online. The stimuli consisted of alternating black–white flashes against a neutral gray background (65 cd/m²). For neurons obtained from the V1 array, this stimulus grid was positioned in a manner that allowed us to coarsely map the spatial RFs across all electrode sites simultaneously. This online RF mapping was used to determine stimulus placement in the main experiment. Although it was not possible to determine the optimal stimulus parameters (orientation, size, direction of motion), the chosen stimulus parameters did evoke vigorous visual responses for most of the V1 neurons and multiunits that we sampled, and therefore, we assumed from this that our stimuli were effective for the purpose of this study. For SC neurons, a delayed saccade task was also used to characterize whether the neurons had visual and/or motor response properties using previously established methods (21). The location of the RFs for V1 neurons fell in the lower left hemisphere, a few degrees below the horizontal meridian, ~5° to 10° eccentric from the fovea. The RFs of SC neurons were generally left or right of the fovea and were above, below, or very near the horizontal meridian at eccentricities ranging from 6° to 24°, with the most frequent eccentricity at ~9° (mode = 8.8). The array was rotated and organized to place the oddball at the center or opposite the RF.

The animals then performed the main task. Specifically, on a given trial (Fig. 1), the animal fixated an FP (black Gaussian-windowed spot, SD = 0.3°), which appeared at the screen center (array-aligned or single item-aligned conditions) (Fig. 1 C and E) or above or below center (saccade end-aligned conditions) (Fig. 1 D and F) orthogonal to the RF at the same eccentricity (exactly ±90° polar angle from RF center). The animals were required to continue fixating on the FP for a 0.5- to 0.7-s random period, after which the goal-irrelevant stimulus/array appeared. The animals were required to continue fixating on the FP for an
additional 0.5–0.7 s, after which the FP stepped from center to one of the specified peripheral locations (array-aligned or item-aligned conditions) (Fig. 1 C and E) or from the peripheral location to center (saccade end-aligned conditions) (Fig. 1 D and F). The animals were then required to launch a saccade to the new location of the FP and to hold fixation on this new location for 0.5–0.7 s within a \( 3 \times 3 \) computer-controlled window, after which a liquid reward was issued. Thus, in the array/item-aligned case, the goal-irrelevant but salient stimulus (oddball or single item) abruptly appeared IN or OPP the RF, whereas in the saccade end-aligned case, the goal-irrelevant stimulus (oddball or single item) was brought into the RF via the saccade to screen center. Importantly, when the eyes were at center in either condition, the stimulus display was the same. Visually evoked responses were measured during the stimulus-aligned vs. saccade end-aligned time points, which are highlighted by the black outlines in the key frames of the illustration in Fig. 1 C–F.

**Data Analyses.**

**Single unit and multiunit recordings.** Single units were isolated online using a window discriminator and confirmed offline using spike-sorting software (Plexon Inc.). Spikes were convolved with a function that resembled an excitatory postsynaptic potential (49), with rise and decay values of 5 and 20 ms, respectively. A total of 94 neurons were isolated (38 V1, 31 SCs, 25 SCI). Using the microelectrode array in V1, several electrodes yielded reliable visually evoked multiunit spiking activity and showed qualitatively similar results to the V1 single units. Therefore, for the main analyses, we combined V1 single units (\( n = 38 \)) and multiunit sites (\( n = 55 \)) for a total of \( n = 93 \). Thus, although V1 was represented by a larger sample size, yielding potentially greater statistical power, this gave additional support for our hypothesis, because SCs neurons still showed a more robust and earlier saliency representation.

**SC neuron classification.** The SC is composed of two dominant functional layers (9, 10), a visual-only superficial layer (SCs) and a multisensory–cognitive–motor-related intermediate layer (SCI). SC neurons were functionally classified as visual SCs or visuo-motor SCI based on their discharge characteristics using a visual RF mapping procedure (21) to determine the presence of a visual component and a delayed saccade task to determine the presence of a motor component using previously established methods (21, 31). Briefly, neurons were defined as having a visual component if the visual mapping procedure yielded the presence of a localized visual RF (21). Neurons were defined as having a motor component if the average firing rate around the time of the saccade (\(-25 \pm 25 \) ms relative to saccade onset) into the neuron’s preferred visual RF was significantly greater than a presaccade baseline period (\(-150 \) to \(-50 \) ms relative to saccade onset).

**Data normalization.** The normalization procedure was similar to conventional normalization to the maximum firing rate, except that we scaled the firing rate of each neuron to its minimum and maximum values evoked by the single item within the relevant time window (from stimulus onset for 500 ms). Specifically, for each neuron, neuronal discharge rates were normalized to the minimum and maximum values of the single-item condition (which always yielded the greatest response) using a zero to one rescaling of the spike density function with the following:

\[
SDF_{\text{normalized}} = \frac{SDF - \min(\text{single item } SDF)}{\max(\text{single item } SDF) - \min(\text{single item } SDF)}
\]

where \( SDF \) is the original spike density function (averaged across trials) for a given condition, and \( \min(\text{single item } SDF) \) and \( \max(\text{single item } SDF) \) are the minimum and maximum values, respectively, within the poststimulus period (0–500 ms) of the single-item condition. Thus, when normalizing the array condition, for example, its response can be seen as a proportion of the maximum response possible using a unitary item. This ensures that the relative differences between conditions for a given neuron are retained. This also makes the percentage surround suppression index very intuitive and easy to compute, because the response curves in the array condition will always be some proportion of the maximum response elicited by the single item.

**Latency and magnitude indices.** VROL, SROL, and SSOL were computed for each neuron when possible (i.e., when the neuron exhibited each of these properties). We used an established statistical method used by others in the attention selection literature (10, 50, 51), which involves a running Wilcoxon rank sum test at a fixed alpha level (\( P < 0.05 \)). This statistical method has been shown to be comparable with conventional receiver operating characteristic analysis (51) for determining neuronal selection times and therefore, provides a reasonable estimate of the latencies and selection times comparable with other studies. The test was run on a temporally averaged moving window at every millisecond from 0 to 300 ms. Specifically, VROL was defined as the time in which activation (averaged over a moving 5-ms window) was significantly greater than a prestimulus baseline (single item-aligned condition: \(-100 \) ms to stimulus onset; saccade end-aligned condition: \(-200 \) to \(-100 \) ms relative saccade onset). SROL was defined as the time in which activation (averaged over a moving 50-ms window) was significantly greater for oddball IN vs. oddball OPP condition. We used a longer window here compared with VROL, because the dynamics of this process was slower and more variable, and the longer window yielded more reliable results. SSOL was defined similarly to SROL, but instead of comparing oddball IN with OPP conditions, the single-item IN condition (no surround) was compared with the oddball IN condition (surround). The latency indices were verified by observing the estimated VROL, SROL, and SSOL of each neuron plotted against its spike density function.

Because surround suppression emerged at noticeably different time periods across the brain areas (Fig. 3), we computed surround suppression magnitude indices during the peak response and later, during a sustained portion of the response. The surround suppression index was defined as the ratio of the response evoked by the single item relative to the response evoked by the array. The time of the peak response differed for each neuron and brain area but in general, ranged from \( -40 \) to 100 ms post-stimulus onset. The sustained period was defined as the period from the VROL of a given neuron for 300 ms.
**Fig. S1.** The time course of saliency representations in V1 and SC (absolute firing rates). (A–D) Population average responses for V1 (blue; \( n = 93 \)) and SCs (red; \( n = 31 \)) across conditions. These results were derived from the same data as in Fig. 2, except here, they are non-normalized absolute firing rates. The tick marks immediately above the x axis in A–D indicate the points where the oddball IN response was significantly greater than the oddball OPP response (\( P < 0.05 \), Wilcoxon signed rank test at 10-ms intervals, Bonferroni–Holm corrected). (E and F) Cumulative distributions of VROL (solid traces) and SROL (dotted traces), with the relative median latencies indicated by the vertical lines with arrows. *\( P < 0.05 \), rank sum test.

**Fig. S2.** Feature preferences. Averaged population spike density functions for preferred and non-preferred stimulus features (orientation, color) for V1 (A and B) and SCs (C and D).
Fig. S3. The time course of saliency representations in V1 (units only) and SC. (A–D) Normalized population average responses for V1 (blue; n = 38; monkeys D and Y) and SCs (red; n = 31; monkeys I and U) when the salient oddball appeared abruptly in the RF (A, C, and E; array-aligned condition) or was brought there via a saccade (B, D, and F; saccade end-aligned condition). The tick marks immediately above the x axis in A–D indicate the points where the oddball IN response was significantly greater than the oddball OPP response (P < 0.05, Wilcoxon signed rank test at 10-ms intervals, Bonferroni–Holm corrected). (E and F) Cumulative distributions of VROL (solid traces) and SROL (dotted traces), with the relative median latencies indicated by the vertical lines with arrows. ns, Not significant. *P < 0.05, rank sum test.

Fig. S4. The time course of saliency representations in V1 and SC (overlapping vs. nonoverlapping RFs). Comparison of VROL and SROL when RFs were overlapping or nonoverlapping between brain areas. As described in Materials and Methods, V1 RFs were clustered in the lower left visual field at 5° to 10° eccentricity from the fovea, whereas SCs RFs were sampled widely across the visual field, with little direct RF overlap as our V1 sample. To examine potential differences between overlapping and nonoverlapping RFs between brain areas, we compared our V1 sample with a subset of SCs neurons with RFs that were within the same eccentricity and lower visual field as V1 (overlapping condition) and a subset of SCs neurons with RFs that were outside this range (nonoverlapping). (A–D) Cumulative distributions of VROLs (solid traces) and SROLs (dotted traces) for overlapping (A and C) and nonoverlapping (B and D) RFs. Median latencies indicated by the vertical lines with arrows. ns, Not significant. *P < 0.05, rank sum test.
Fig. S5. Surround suppression in V1 and SC (absolute firing rates). (A–D) Population average responses for V1 (blue; \(n=93\)) and SCs (red; \(n=31\)) across conditions. These results were derived from the same data as in Fig. 3, except here, they are nonnormalized absolute firing rates. The tick marks immediately above the x axis in A–D indicate the points where the single-item IN response was significantly greater than the oddball IN response (\(P<0.05\), Wilcoxon signed rank test at 10-ms intervals, Bonferroni–Holm corrected). (E–H) Averaged percentage suppression across V1 (\(n=93\)) and SCs (\(n=31\)) recordings. (I and J) Cumulative distributions showing a comparison of the SSOL (dotted traces) relative to VROL (solid traces). ns, Not significant. *\(P<0.05\), rank sum test.

Fig. S6. Surround suppression in V1 (units only) and SC. (A–D) Normalized population average responses for V1 (blue; \(n=38\); monkeys D and Y) and SCs (red; \(n=31\); monkeys I and U) comparing the single-item IN condition (black traces; no surround) with the oddball IN condition (colored traces; surround) aligned on array/item onset (A and C) and saccade end (B and D). The tick marks immediately above the x axis in A–D indicate the points where the single-item IN response was significantly greater than the oddball IN response (\(P<0.05\), Wilcoxon signed rank test at 10-ms intervals, Bonferroni–Holm corrected). (E–H) Averaged percentage suppression across V1 (\(n=38\)) and SCs (\(n=31\)) recordings. Percentage suppression was computed from the ratio of response evoked by the single item (no surround) vs. the array (surround) with the oddball IN the RF and was computed during the peak and during a sustained period of the response (Materials and Methods). (I and J) Cumulative distributions showing a comparison of the SSOL (dotted traces) relative to VROL (solid traces). ns, Not significant. *\(P<0.05\), rank sum test.
Fig. S7. Surround suppression in V1 and SC (overlapping vs. nonoverlapping RFs). This figure shows the surround suppression results with overlapping vs. nonoverlapping RFs between brain areas (as detailed in Fig. S4). (A–D) Cumulative distributions of VROLs (solid traces) and SSOLs (dotted traces) for overlapping (A and C) and nonoverlapping (B and D) RFs. Median latencies are indicated by the vertical lines with arrows. (E–L) Mean percentage suppression for overlapping (E–H) and nonoverlapping (I–L) RFs between brain areas. ns, Not significant. *P < 0.05, rank sum test.