Supplementary Material

Supplementary Analysis 1: Power Analysis

For Experiment 1, given a somewhat "unique" experimental task that asked participants to actually judge whether an object image might be a scene, we conservatively estimated that if such an effect exists, it may only be a low-to-medium one (i.e., $\eta_P^2 = 0.05$). Moreover, we also decided upon 0.9 as the power level—which is higher than the standard desired power level of 0.8—to minimize the probability of a Type-II error. Thus, together with an alpha level of 0.05, a power analysis revealed that a minimum of 35 participants was needed to detect the effect that we set out to test in Experiment 1. However, we ended up recruiting 50 participants because we collected data remotely via Amazon Mechanical Turk (MTurk) and anticipated a 15% attrition rate, given "remote" participants may be more likely to not follow the instructions correctly, compared to "in-person" participants. That said, to our good fortune, all 50 participants in fact followed the instructions, and we thereby ended up with a larger sample size than specified in the power analysis.

For the fMRI experiments (Experiments 2 and 3), we examined numerous similar existing studies—namely studies that also used a region-of-interest approach to investigate high-level cortical visual processing—as a reference and estimated our study to have a medium effect size (i.e., $\eta_P^2 = 0.10$). Thus, together with an alpha level of 0.05 and the standard desired level of power at 0.8, power analysis revealed that a minimum of 14 participants was needed for Experiment 2, and 11 participants for Experiment 3. In both experiments, we scanned more participants than the sample size specified by the power analysis in anticipation of data loss due to participant no-shows or excessive head motion during scanning. With a final number of 15 participants for Experiment 2, and 14 participants for Experiment 3, we collected a couple of more participants than specified by the power analyses.

For Experiment 4, based on the results of a pilot study, we estimated an odds ratio of 3 and a proportion of discordant pairs of 0.45. And just like in Experiment 1, we decided upon 0.9 as the desired power level. Together with an alpha level of 0.05, a power analysis revealed that a minimum of 94 participants was needed to detect the effect that we set out to test in Experiment 4. We ended up recruiting 100 participants in anticipation of participant attrition. With a final number of 99 participants, we collected more participant data than specified in the power analysis.

Supplementary Analysis 2: Consistency of ROI response patterns between using the typical threshold and a more lenient threshold for the Localizer runs in Experiment 3

To check whether having a smaller sample size for some ROIs and/or having unmatched unilateral versus bilateral ROIs might have affected the results in Experiment 3, we defined the ROIs in the missing participants using a lower threshold (a minimum of p<.01) for the contrast in the independent Localizer runs and examined the neural response of each ROI with these additional data.

With this more lenient threshold, we were able to obtain bilateral ROIs in all 14 participants for PPA and OPA, and 12 out of 13 participants for RSC and LOC. Figure S1 showed the aggregated neural response for each ROI having included the additional data—we found consistent response patterns as those reported in the manuscript. Moreover, we also examined the neural response of the ROIs from each hemisphere separately and again found a consistent pattern (see Figure S2). Thus, having a smaller sample size for some ROIs and different numbers of unilateral/bilateral ROIs did not affect the results.

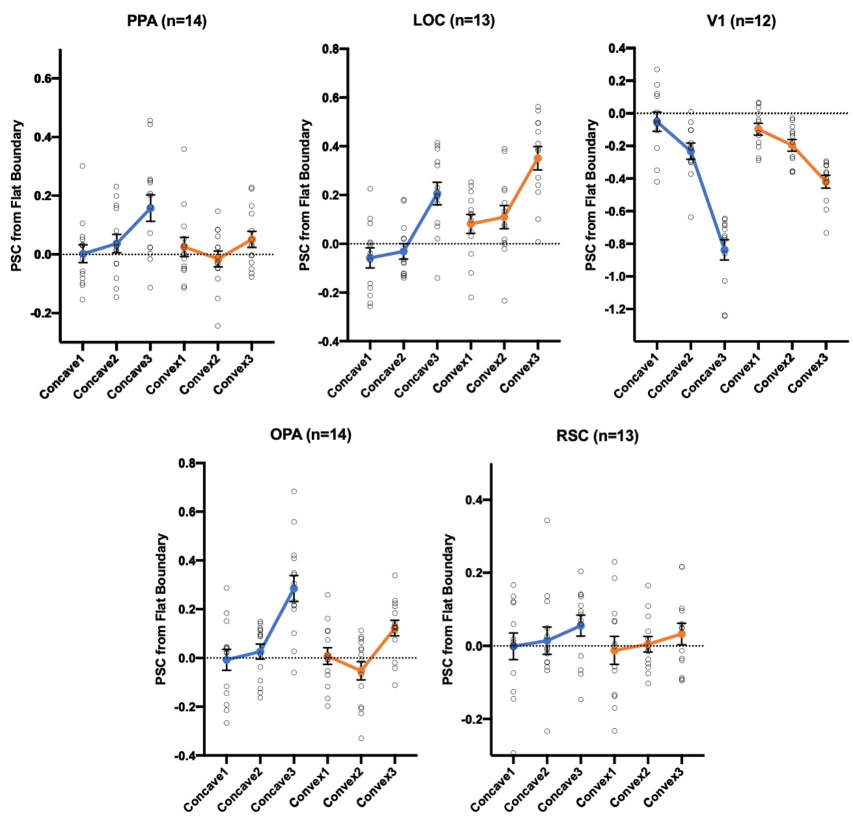


Figure S1. Neural response patterns that include additional ROIs defined with a lower threshold (a minimum of p<.01) using the Localizer contrasts in Experiment 3. We found consistent response patterns as those reported in the manuscript. Error bars represent the standard error of the mean; n represents the number of participants in which that ROI was defined.

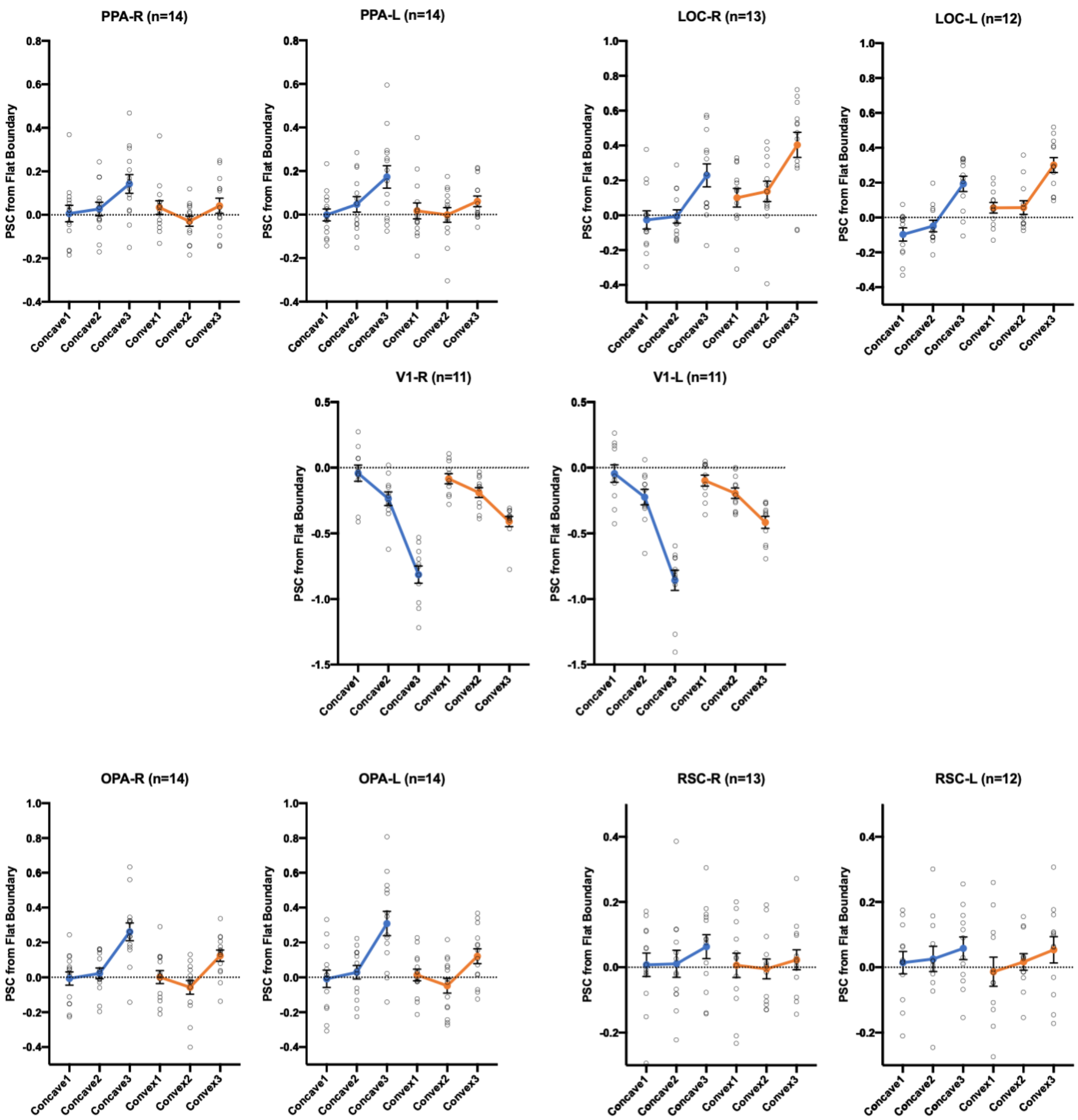


Figure S2. Neural response patterns that include additional ROIs defined with a lower threshold (a minimum of p<.01) using the same Localizer contrasts in Experiment 3, separated by hemispheres. We found consistent results in both hemispheres, which are also consistent with the results reported in the manuscript. Error bars represent the standard error of the mean; n represents the number of participants in which that ROI was defined.

Supplementary Analysis 3: Split-half analysis for Experiment 2 and 3

We split the data into halves by odd and even runs to test for the reliability of the findings. we discussed the relevant results for Experiment 2 and 3 separately.

Experiment 2

To evaluate the reliability of our findings in Experiment 2, we examined whether 1) PPA and OPA consistently show an overall greater response for Concave over Convex conditions, with a selectively greater response for Concave over Convex Objects, and 2) LOC consistently shows a greater response for Convex over Concave Objects and Buildings, when data are split into odd and even halves.

See Figure S3 for the results of all the ROIs in odd versus even runs in Experiment 3. We first examined the results in PPA using a 2 (Half: Odd, Even) x 2 (Category: Buildings, Objects) x 2 (Condition: Concave, Convex) repeated-measures ANOVA. Consistent with the combined results reported in the manuscript, we found a significant main effect of Condition ($F_{(1,14)}$=17.118, p=0.001, η_p^2=.550), with a significantly greater response to Concave over Convex conditions in both odd and even runs. Consistently, we also found a significant Category x Condition interaction ($F_{(1,14)}$=21.362, p<.001, η_p^2=.604), with a greater response to Concave over Convex Objects (post-hoc comparison; odd: p<.001; even: p=.002) but no significant difference between Concave and Convex Buildings (odd: p=.771; even: p=.908) in both halves of the data, replicating the combined results reported in the manuscript.

Just like in PPA, we used a 2 (Half: Odd, Even) x 2 (Category: Buildings, Objects) x 2 (Condition: Concave, Convex) repeated-measures ANOVA to directly examine the results in OPA. Consistent with the combined results reported in the manuscript, we found a significant main effect of Condition ($F_{(1,13)}$=31.039, p<0.001, η_p^2=.705), with a greater response for Concave over Convex Conditions in both odd and even halves. Moreover, we also found a significant Category x Condition interaction ($F_{(1,13)}$=6.489, p=.024, η_p^2=.333), with a significantly greater response to Concave over Convex Objects (odd: p<.001; even: p=.011) but no significant difference between Concave and Convex Buildings (odd: p=.249; even: p=.193) in both halves of the data, replicating the combined results reported in the manuscript.

Finally, we also examined the results of LOC. Just like in PPA and OPA, we used a 2 (Half: Odd, Even) x 2 (Category: Buildings, Objects) x 2 (Condition: Concave, Convex) repeated-measures ANOVA to directly examined the results. Consistent with the combined results reported in the manuscript, we found a significant main effect of Condition ($F_{(1,14)}$=37.997, p<0.001, η_p^2=.731), with a greater response for Convex over Concave Conditions in both odd and even runs. Moreover, we found a significant Category x Condition interaction ($F_{(1,14)}$=10.104, p=.007, η_p^2=.419), with a greater response to Convex over Concave Buildings relative to Convex over Concave Objects. Post-hoc comparison revealed a significantly greater response to Convex over Concave Buildings in both halves of the data, (p<.001 for both odd and even runs), a significantly greater response to Convex over

Concave Objects in the even runs (p=.010), and a numerically greater response to Convex over Concave Objects in the odd runs (mean difference in PSC between Concave vs. Convex Objects=.099, p=.177). Together, these results replicated the combined results reported in the manuscript.

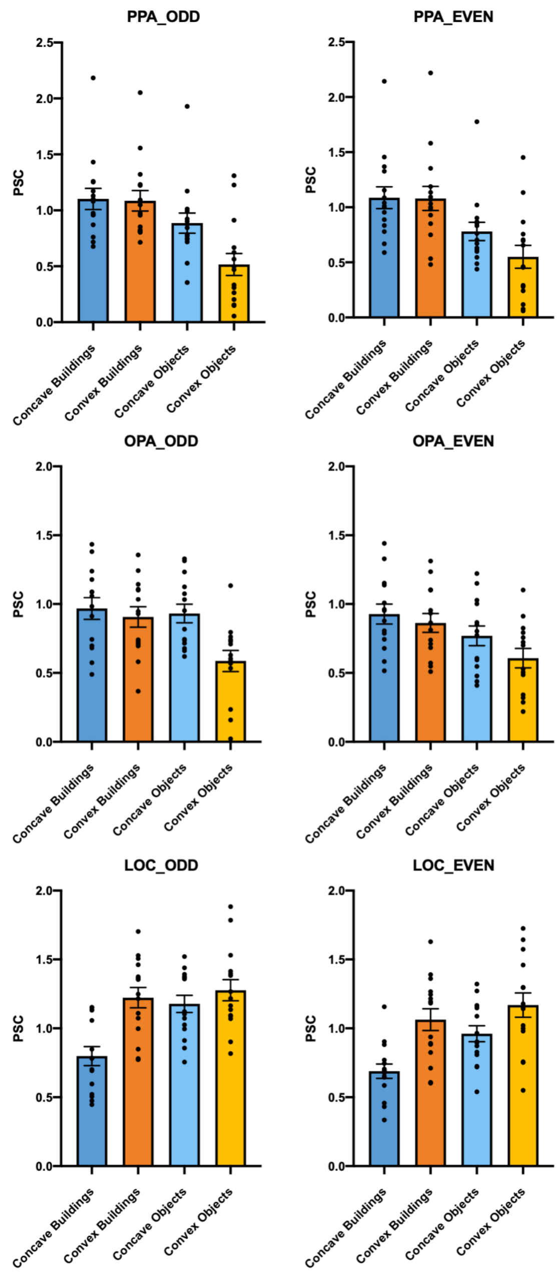


Figure S3. Neural response of PPA, OPA and LOC in the odd and even runs of Experiment 2. We found consistent results in both halves of the data, and replicated the combined results reported in the manuscript. Error bars represent the standard error of the mean.

Experiment 3

To evaluate the reliability of our main findings in Experiment 3, we examined whether 1) PPA and OPA consistently a selectively greater sensitivity for changes in Concave boundaries over Convex boundaries, and 2) LOC shows an overall greater response for Convex over Concave boundaries, with equal sensitivity to changes in both concavity and convexity, when data are split into odd and even halves.

See Figure S4 for the results of all the ROIs in odd versus even runs in Experiment 3. We first examined the results in PPA using a 2 (Half: Odd, Even) x 2 (Boundary Type: Concave, Convex) x 3 (Angle 1,2,3) repeated measures ANOVA. Consistent with the combined results reported in the manuscript, we found a significant Boundary Type x Angle interaction ($F_{(2,26)}$=4.270, p=0.025, η_p^2=.247), with a significant Boundary Type x Angle linear trend interaction ($F_{(1,13)}$=9.296, p=0.009, η_p^2=.417), indicating a selective sensitivity to changes in concavity over convexity. Moreover, we found no significant Half x Boundary Type x Angle interaction ($F_{(2,26)}$=2.115, p=0.141, η_p^2=.140), and no significant Half x Boundary Type x Angle linear trend interaction ($F_{(1,13)}$=2.817, p=0.117, η_p^2=.178), indicating no difference in PPA's selective sensitivity to concavity over convexity between the odd versus even halves of the data.

Just like in PPA, we directly examined the results of OPA using a 2 (Half: Odd, Even) x 2 (Boundary Type: Concave, Convex) x 3 (Angle: 1,2,3) repeated measures ANOVA. Consistent with the combined results reported in the manuscript, we found a significant Boundary Type x Angle interaction ($F_{(2,24)}$=3.968, p=0.032, η_p^2=.248), with a significant Boundary Type x Angle linear trend interaction ($F_{(1,12)}$=6.213, p=0.028, η_p^2=.341), indicating a selective sensitivity to changes in concavity over convexity. Moreover, we found no significant Half x Boundary Type x Angle interaction ($F_{(2,24)}$=.368, p=0.696, η_p^2=.030), with no significant Half x Boundary Type x Angle linear trend interaction ($F_{(1,12)}$=0.118, p=0.737, η_p^2=.010), indicating no difference in OPA's selective sensitivity to concavity over convexity between the odd versus even halves of the data.

Just like in PPA and OPA, we also directly examined the results of LOC using a 2 (Half: Odd, Even) x 2 (Boundary Type: Concave, Convex) x 3 (Angle 1,2,3) repeated measures ANOVA. Consistent with the combined results reported in the manuscript, we found a significant main effect of Boundary Type ($F_{(1,12)}$=21.099, p=0.001, η_p^2=.637), with an overall greater response to Convex over Concave conditions. Importantly, we found no significant Half x Boundary Type interaction ($F_{(1,12)}$=0.267, p=0.615, η_p^2=.022), indicating no difference in LOC's selective response to Convex boundaries between odd versus even runs. In addition, we also found a significant main effect of Angle ($F_{(2,24)}$=38.993, p<.001, η_p^2=.765), with no significant Boundary Type x Angle interaction ($F_{(2,24)}$=.021, p=0.979, η_p^2=.002), indicating an increase of LOC response as Angle increases in both Concave and Convex boundaries. Importantly, we found no significant Half x Boundary Type x Angle interaction ($F_{(2,24)}$=0.488, p=0.620, η_p^2=.039), revealing no difference in LOC's sensitivity to changes in both concavity and convexity of the boundaries between the odd and even halves of the data.

Together, we found consistent results as those reported in the manuscript in both halves of the data, in both Experiment 2 and 3, providing evidence for the reliability of the results.

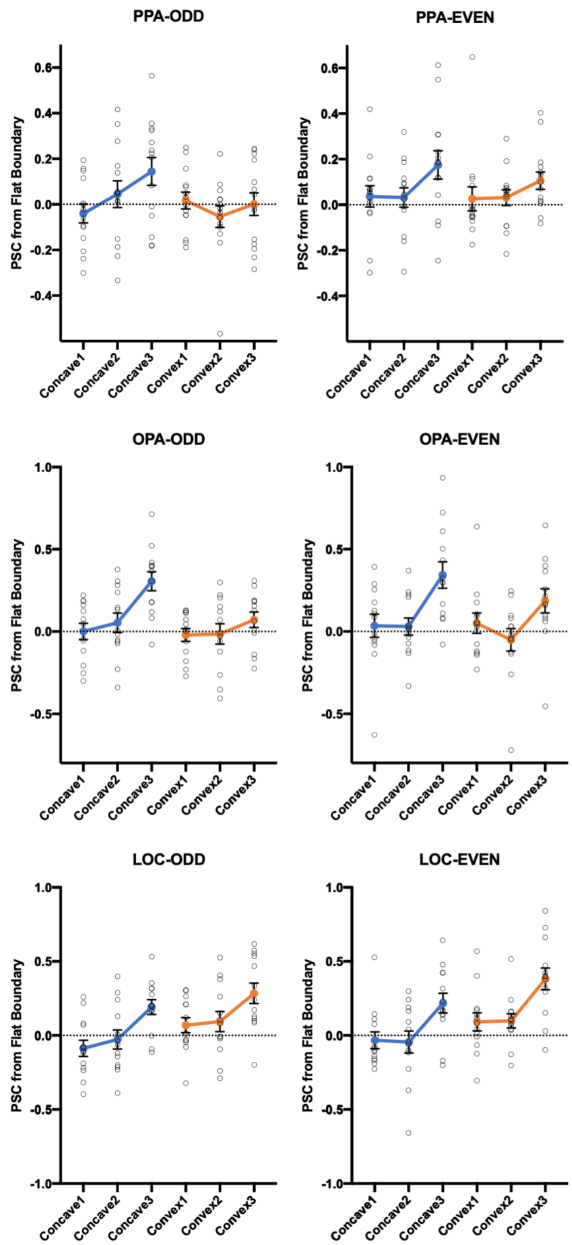


Figure S4. Neural response of PPA, OPA and LOC in odd and even runs of Experiment 3. We found consistent results in both halves of the data, and replicated the combined results reported in the manuscript. Error bars represent the standard error of the mean.

Supplementary Analysis 4: Consistency of RSC results in Experiment 2 and 3

To ensure that the null results in RSC are not merely due to having less functionally defined ROIs, we defined RSC in the missing participants with a lowered threshold for the Scene-Object contrast ($p<.01$) in the independent Localizer runs and rerun the same statistical analysis as those reported in the paper.

In Experiment 2, we were able to define RSC in at least one hemisphere of all 15 participants. Using a 2 (Category: Buildings, Objects) x 2 (Condition: Concave, Convex) repeated-measures ANOVA, we found a significant main effect of Category ($F_{(1,14)}=108.463$, $p<0.001$, $\eta_p^2=.886$), with no significant main effect of Condition ($F_{(1,14)}=2.356$, $p=0.147, \eta_p^2=.144$), and no significant Category x Condition interaction ($F_{(1,14)}=.226$, $p=0.642, \eta_p^2=.016$), consistent with the results reported in the manuscript.

In Experiment 3, we were able to define RSC in at least one hemisphere of 13 participants. Using a 2 (Boundary Type: Concave, Convex) x 3 (Angle: 1, 2, 3) repeated-measures ANOVA, we found no significant main effect of Boundary Type ($F_{(1,12)}=.778$, $p=0.395$, $\eta_p^2=.061$), no significant main effect of Angle ($F_{(2,24)}=1.304$, $p=0.290$, $\eta_p^2=.098$), and no significant Boundary Type x Angle interaction ($F_{(2,24)}=.046$, $p=0.955$, $\eta_p^2=.004$). Moreover, when we further test for RSC's sensitivity to Angle using a planned, three-level (Angle: 1,2,3) repeated-measures ANOVA for the Concave condition and the Convex condition, separately, we consistently found no significant main effect of Angle (Concave: $F_{(2,24)}=.864$, $p=0.434$, $\eta_p^2=.067$; Convex: $F_{(2,24)}=.876$, $p=0.430$, $\eta_p^2=.068$) nor a significant linear increase by Angle (Concave: $F_{(1,12)}=2.332$, $p=0.153$, $\eta_p^2=.163$; Convex: $F_{(1,12)}=1.479$, $p=0.247$, $\eta_p^2=.110$). Together, these results are consistent with the results reported in the manuscript.

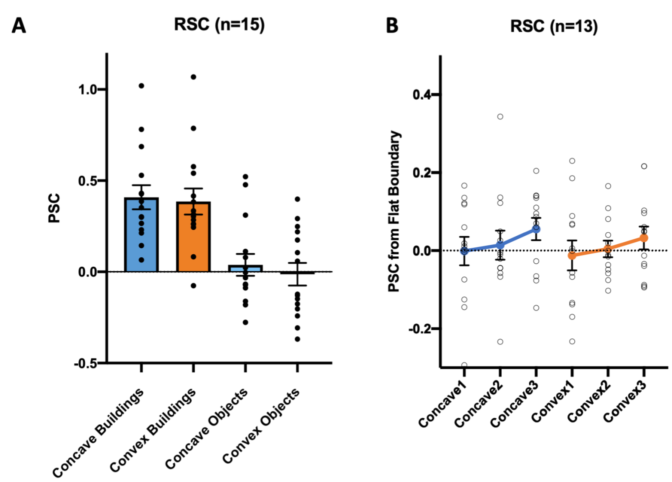


Figure S5. Neural response of RSC when including the ROIs defined in the missing participants using a lower threshold (a minimum of $p<.01$ for Scenes-Objects in the independent Localizer runs) in Experiment 2 (**A**) and Experiment 3 (**B**). We found consistent response patterns as those reported in the manuscript. Error bars represent the standard error of the mean; n represents the number of participants in which that ROI was defined.

Supplementary Analysis 5: Whole-brain analysis of Experiment 3, thresholded with a false discovery rate at q<.05

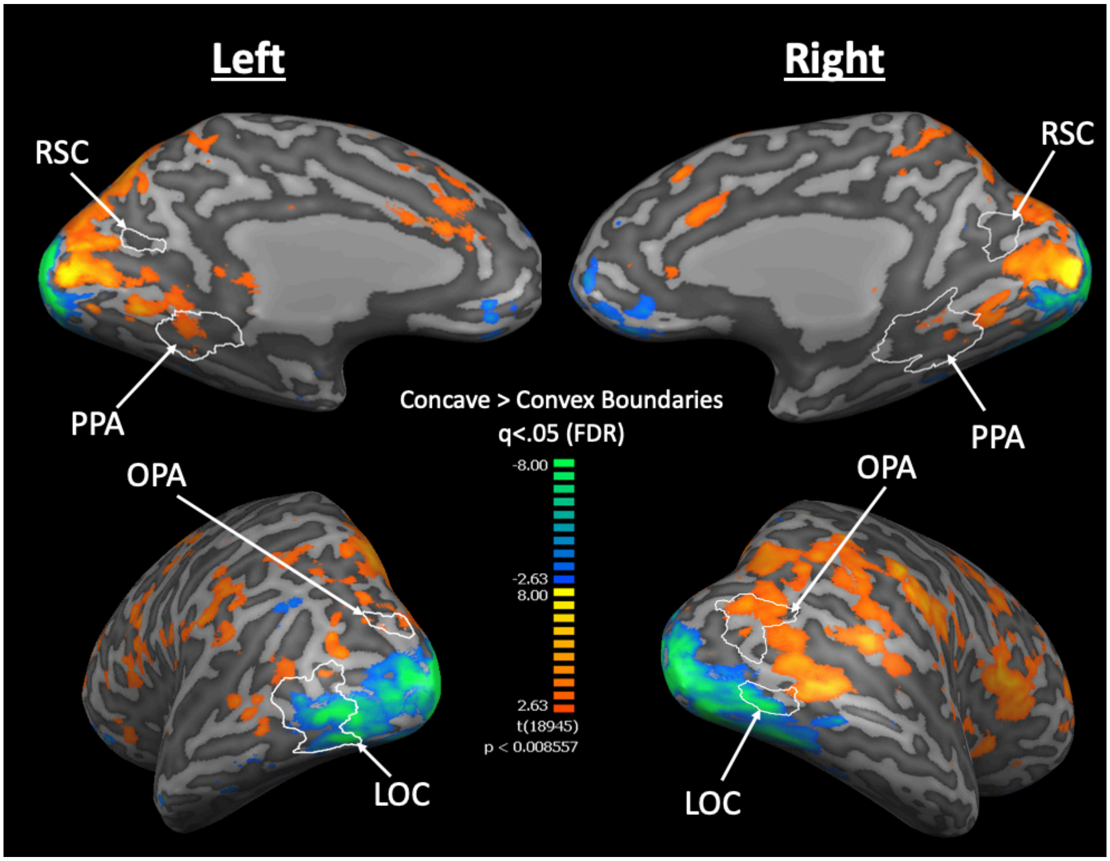


Figure S6. A group cortical surface map for regions that responded more to Concave than Convex Boundaries (averaged across Angles 1, 2, 3), thresholded with a false discovery rate at q<.05. White lines indicate the ROIs that are functionally defined at the group level using an independent set of Localizer runs. We observed a similar topography of activation as that in Figure 4 in the manuscript, with Concave-selective activations in and around PPA and OPA, and Convex-selective activation in and around LOC. Importantly, we also observed distinct streams of Concave- and Convex-selectivity along the ventral occipitotemporal cortex, leading up to PPA and LOC, distinctively, consistent with Figure 4 in the manuscript.

Supplementary Analysis 6: Replication of Experiment 4 results

To ensure that the response pattern observed in Experiment 4 is reliable, we repeated the experiment on a separate group of 50 participants recruited on Amazon Mechanical Turk; one subject was excluded due to failing an attention check question.

See Figure S6 for the replication results. Consistent with the results reported in Experiment 4, we found that all the Concave shapes received over 70% of scene ratings as opposed to object ratings (Concave 1: 85.71%; Concave 2: 91.83 %; Concave 3: 73.47 %). By contrast, the proportion of scene ratings for Flat and Convex shapes are much lower (scene ratings for Flat: 51.02%; Convex 1: 55.10%; Convex 2: 65.31%; Convex 3: 46.94%). Crucially, when we directly compared the Concave and Convex conditions with the same Angle (e.g., Concave 2 vs. Convex 2) using the McNemar's test, all Concave shapes indeed showed a significantly greater proportion of scene ratings than the corresponding Convex shapes that shared the same Angle ($p<.016$ for all three pairs of comparisons). Together, we replicated the response pattern reported in Experiment 4 with a separate group of participants.

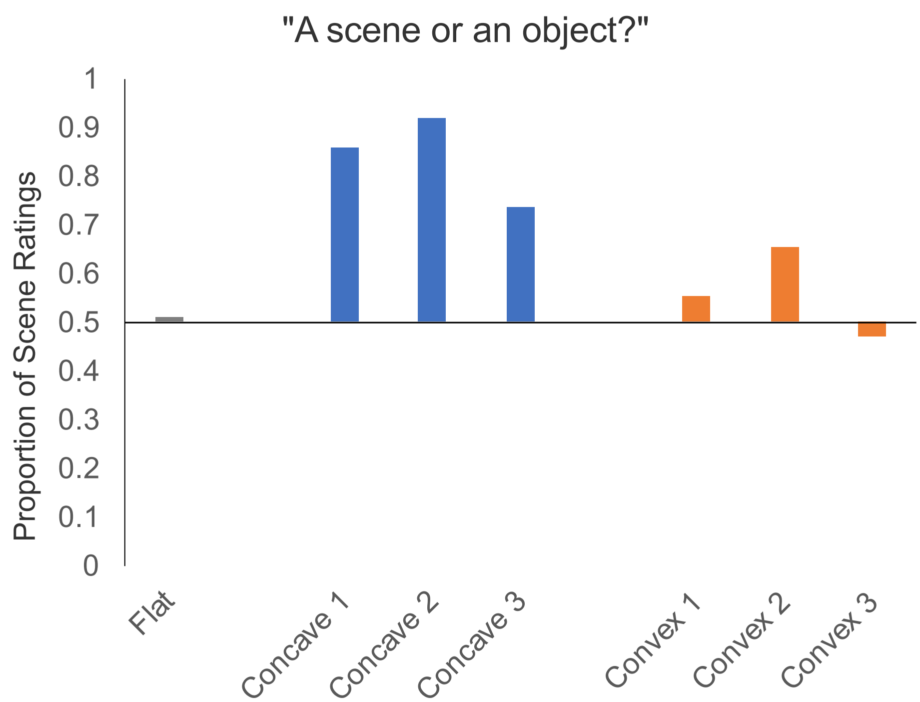


Figure S7. Response pattern from a separate group of 49 participants in Experiment 4. We replicated the response pattern reported in the manuscript.

Supplementary Analysis 7: Behavioral categorization of stimuli in Experiment 3

To test whether the presence/absence of the boundary textures might have affected participants' perception of the stimuli in Experiment 4 as a scene or an object, we conducted the same behavioral experiment with the Experiment 3 stimuli on a separate group of 100 participants recruited on Amazon Mechanical Turk; twelve subjects were excluded due to failing an attention check question. Each participant rated all seven conditions (Flat, Concave 1, 2, 3, Convex 1, 2, 3) that consist of the same boundary texture; the boundary texture was randomly assigned.

See Figure S8 for the results. Consistent with the results reported in Experiment 4, we found that all the Concave conditions received over 60% of scene ratings as opposed to object ratings (Concave 1: 61.36%; Concave 2: 60.23 %; Concave 3: 80.68%). By contrast, the proportions of scene ratings for the Flat and Convex conditions are much lower (scene ratings for Flat: 47.72%; Convex 1: 48.86%; Convex 2: 51.14%; Convex 3: 53.41%). Using a Binomial Test, we found that the proportions of scene ratings for all the Concave conditions were either significantly above chance or trending towards significance (Concave 1: $p=.042$; Concave 2: $p=.069$; Concave 3: $p<.001$), whereas those for the Flat and Convex conditions are not (Flat: $p=.749$; Convex 1: $p=.915$; Convex 2: $p=.915$; Convex 3: $p=.594$), consistent with the results from Experiment 4. Furthermore, when we directly compared the Concave and Convex conditions with the same Angle (e.g., Concave 2 vs. Convex 2) using the McNemar's test, we again found consistent results, with all Concave conditions showing either a significantly greater or at least numerically greater proportion of scene ratings than the corresponding Convex condition that shared the same Angle (Concave 1 vs. Convex 1: $p=.027$; Concave 2 vs. Convex 2: $p=.215$; Concave 3 vs. Convex 3: $p<.001$). Together, we found a response pattern that is consistent with those reported in Experiment 4.

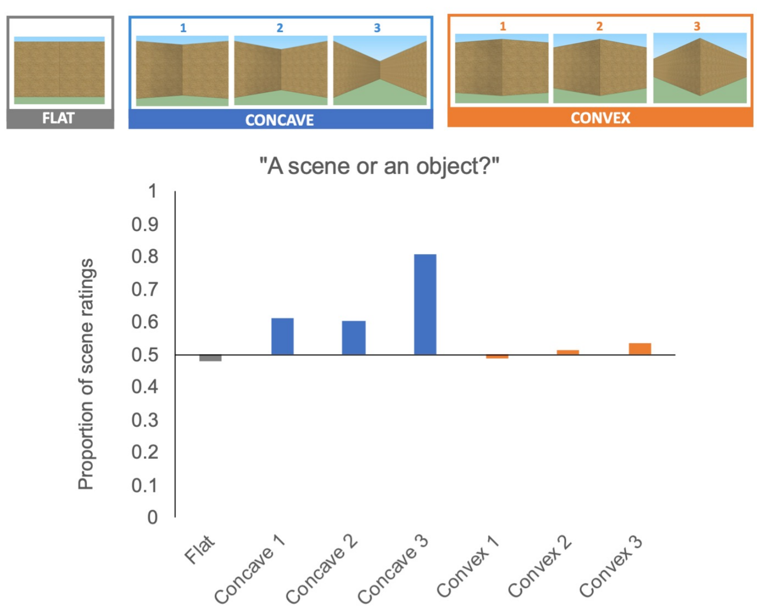
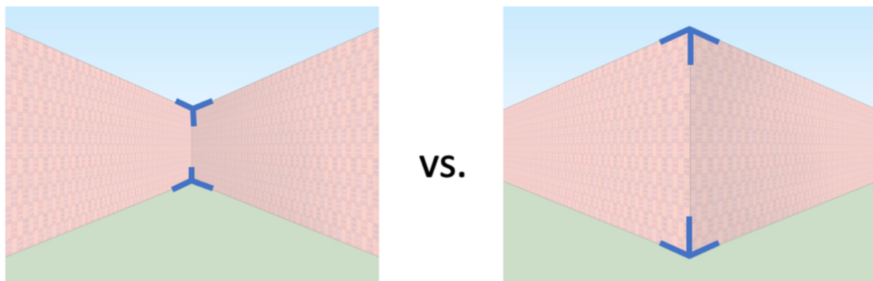


Figure S8. Behavioral categorization of the stimuli from Experiment 3 as either a scene or an object. We found a consistent response pattern of Concave conditions being more scene-like than object-like, relative to Convex conditions, just like in Experiment 4.

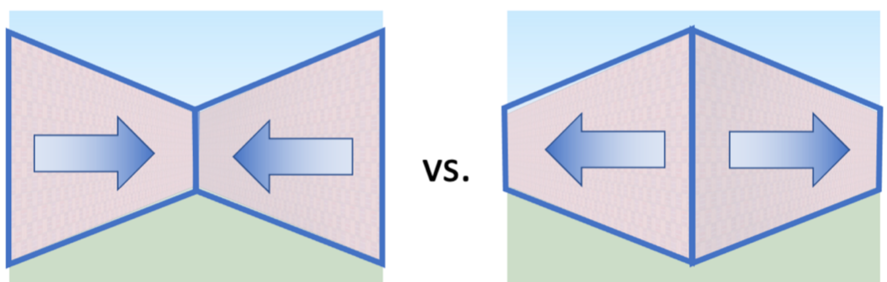
Supplementary Figure S9: Graphic illustration for the different visual cues that are diagnostic of concavity vs. convexity

<u>Different visual cues that are diagnostic of concavity vs. convexity</u>

1. Contour junctions: Concave spaces are usually made up of surfaces with contours conjoining at a **Y-junction**, whereas convex spaces are usually made up of surfaces with contours conjoining at an **arrow-junction**.



2. Surface orientations: 3D surfaces of concavity **converge** in depth, whereas 3D surfaces of convexity **diverge** in depth



3. Texture gradients: The surfaces that compose a concave space usually show **an increasing density and distortion of texture patterns** (i.e., texture gradient) as they converge, whereas surfaces of convexity usually show **a decreasing density and distortion of texture patterns** as they converge