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The role of surface completion on the convexity context effect

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Running Head: Convexity Context Effect

Abstract

In order to represent and interact with our environment, the visual system has to perceptually organize the retinal image into potential objects and their spatial relations. One aspect of perceptual organization is figure-ground segregation, the process of identifying which parts of a scene are figure and which are background. One tendency is for the visual system to assign convex regions as figure and concave regions as ground. Recently, this convexity bias was discovered to increase when the number of repeating figure-ground regions increases. It has been hypothesized that this convexity context effect (CCE) is caused by observers perceptually completing the concave regions into a single background behind the convex figures. If true, then the CCE should occur even when regions are made discontinuous by another surface that partially occludes them but should not occur when regions are discontinuous with no occluding surface to explain the discontinuity. The results of my project partially confirm these predictions in that partially occluded displays produced an equal magnitude CCE as unoccluded displays. However, discontinuous displays without an occluding surface also produced an equal magnitude CCE as unoccluded contiguous displays. Follow-up experiments will address this failure of our control condition.

Introduction

There are a variety of ways that the visual system organizes the light patterns hitting our eyes and transforms this information into representations about the scene before us. Each organizational mechanism has its own function that helps us interpret our world in a certain way. One such kind of perceptual organization is figure-ground segregation. Figure-ground segregation causes us to perceive one region, described as figure, as standing in front of another surrounding region. The surrounding region, otherwise known as ground, is seen as a background to the figure region.

Our perception of figure and ground is dependent on border ownership of the regions in a scene. Borders are composed of edges that surround these regions. The visual system assigns borders to regions so that we may perceive a border belonging to one region and not the other. In **Figure 1**, for example, many people tend to see the border between the black and white regions as belonging to the black region, thus seeing black faces rather than a white vase. It should be noted, however, that border ownership is not always clear cut and can lead to ambiguity of figure-ground organization. If you look at **Figure 1** again and think of the black-white border as belonging to the white region of the image, then the white vase will be more prominent and become the figure while the black faces become ground. This demonstration shows that different border ownership interpretations can affect what we see.

To combat this issue of ambiguity, the visual system uses cues to assign border ownership or in other words, figure-ground segmentation. One cue that affects figure-ground organization is symmetry. Regions that are symmetrical are more often seen as figure than regions that are asymmetrical (Harrower, 1936). A more recently discovered cue that influences figure-ground perception is the meaningfulness of the shape of the regions in a scene (Peterson

& Gibson, 1994). Specifically, when regions are shaped similarly to recognizable objects, we tend to perceive these regions as figure. In order for the visual system to recognize regions as being familiar objects in the real world, it needs to form a mental representation of the region's shape to be matched with the array of object shapes that have been stored in memory. This process indicates that to begin this recognition, the region that carries meaningfulness tends to be regarded as figure.

Another cue for figure-ground segmentation is convexity (Kanizsa & Gerbino, 1976). Specifically, regions with convex borders are more often perceived as figure than are regions with concave borders. Peterson & Salvagio (2008) discovered an extension of this cue. In their study, the researchers examined how the convexity cue promotes a bias for figure using the figure-ground stimuli. **Figure 2** illustrates the stimuli they used (upper panel) and how convex and concave regions were defined (lower panel). To see if this convexity bias was impacted by the context of the figure-ground stimuli, they manipulated the context of a given figure-ground display by varying the number of figure-ground regions (**Figure 3**). As the number of figure-ground regions increased, they found that the bias for convex regions as figure increased in a seemingly proportional manner (**Figure 4**). When the number of figure-ground regions was limited to 2, the bias for convexity was weak and almost ambiguous. It grew stronger as more regions were added to the figure-ground stimuli. This relationship between the context of region numbers and convexity bias was coined as the context convexity effect (CCE).

Peterson & Salvagio (2008) suggested several mechanisms by which the CCE might be caused. One is a weight linkage mechanism where certain regions are given a weight that denotes the likelihood that its properties coincide with objects in the environment. In other words, convex regions have slightly higher weight than concave regions. With a lower weight, the suppression of homogeneously colored concave regions spreads across similar regions in the figure-ground displays. This increases the weight difference between convex and concave regions, leading to the higher chance that convex regions are perceived as figure. In addition, it was noted that perceptual completion may be linked to the weight hypothesis for the CCE. The suggestion for perceptual completion as an explanation for the CCE was the focus of the current study.

As a measure of figure-ground perception, the CCE also indirectly suggests the occurrence of surface completion. The current study was designed to test the hypothesis that the CCE is caused by perceiving the concave regions as a complete background behind the convex regions. The CCE observed in Peterson's study suggested that behind the convex regions perceived as figure, the concave regions were interpreted as a continuous background surface that was occluded by the convex regions. This perception of a contiguous background becomes more noticeable when there is an increase in region numbers. If you look at **Figure 3a** and compare it to **Figure 3d**, the black concave region in **Figure 3a** is more likely to be perceived as an individual concave region, while the black concave regions of **Figure 3d** are more likely to be perceived as a complete background and not as individual concave regions.

To test the hypothesis that the CCE is caused by completion, the figure-ground stimuli were made discontinuous in two ways (see the bottom row of **Figure 5**). In one condition, a discontinuity was introduced that was caused by the presence of an occluding surface in front of the figure-ground stimuli. The presence of an occluder provides visual cues that should support the completion of a background surface. This would make it seem like even though the stimulus was discontinuous as an image, it is none the less a continuous surface behind the occluder. Thus, it was predicted that the resulting CCE would reflect the implied number of regions just as in the Peterson & Salvagio (2008) study. In another condition, a discontinuity was introduced that was simply a gap between regions, creating separate figure-ground stimuli each with fewer regions. Adding a gap between regions should disrupt the CCE because the completion of a background surface is no longer supported by the visual information. Thus, it was predicted that the resulting CCE would be smaller than the base CCE.

Methods

Subjects

19 students (18 female, 3 male) from the University of Iowa were recruited using the SONA system (mean age of 19). Participants had normal or corrected-to-normal visual acuity. Color vision was assessed using Ishihara's Design Charts for Color Deficiency of Unlettered Persons (2006); none of the participants was found to have any color deficiencies. Course credit was given as compensation for their participation.

Apparatus

Visual stimulus presentation was controlled by MATLAB software and the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997) running on a Mac Mini computer. A 24-in. LCD Eizo color monitor was used. Participants were placed at a fixed viewing distance of 59 cm. with the help of a chin rest. They used the “f” and “j” keys (operated with their left and right index fingers, respectively) on a standard computer keyboard for their responses.

Stimuli

Figure-ground stimuli from the Peterson & Salvagio (2008) study were used. Each stimulus consisted of a variable number of repeating black and white patterns of vertical regions separated by curvy borders with varying concavities and convexities. There were four conditions used in this study (**Figure 5**). In two (top row), the stimuli were continuous. In the fewer-region condition (see **Figure 5a**), the stimuli had only three regions. Stimuli in this condition were 3.4˚ W × 5.82˚ H. In the more-regions condition, (see **Figure 5b**) the stimuli had eight regions. Stimuli in this condition were 11.61˚ W × 5.82˚ H. In the other two conditions, the stimuli were discontinuous (bottom row). In the gap condition, an eight-region display was disrupted by a 4.37˚ W gap (see **Figure 5c**). In the occluer condition, an eight-region display was disrupted by a green 4.37˚ W × 10.27˚ H rectangular occluder (see **Figure 5d**). A red square probe (0.29˚ W × 0.29˚ H), needed for the experimental task, was placed on top of all the figure-ground stimuli.

Task and Design

A 2 (number of regions) X 2 (display continuity) within-subjects design was used (see **Figure 4**). Participants reported whether a red probe square appeared to be on a figure region or a ground region. The dependent measure was the probability that the convex region was reported as figure, P(convex = figure).

The two continuous conditions (top row of **Figure 5**) provided a measure of the base CCE. We expected it to show a difference between the three- and eight-region displays. The discontinuous conditions provided a test of the hypothesis. If the hypothesis is correct, the CCE should be small in the gap condition (perhaps the same size as in the three-region continuous condition) and large in the occluder condition, as large as in the continuous eight-region condition.

The probe was equally likely to appear in a convex or a concave region, which was equally likely to be black or white. For the continuous displays, the probe was presented to the left or right (equally often) of the center boundary. For the discontinuous displays, it was presented to the left or the right (equally often) of either the left-most or right-most boundary (see **Figure 5**).

Procedure

The experiment took place in a single one-hour session. Following the informed consent process, participants were given written instructions describing the task. They then completed 2 blocks of 32 practice trials during which they could ask questions of the experimenter who remained present. In the first practice block, speed was not stressed, and participants were allowed to take the time they needed to adjust to the task. The second practice block was speed stressed and would resemble the remainder of the experimental blocks. Since there was no time limit for how long the figure-ground displays stayed on the screen, it was important that speed was emphasized to perform as fast as they could. After the practice, they completed 9 blocks of 64 trials each, yielding a total of 144 observations per condition. Each trial began with a fixation cross presented at the center of the gray screen before being replaced by the figure-ground stimuli. The figure-ground stimuli remained on the screen until the participant responded by pressing the “f” or “j” key. If participants perceived the probe to be on a figure region, they were to press the “f” key on the keyboard. If they perceived the probe to be on a ground region, they were to press the “j” key. Once a response was made, the next trial would begin.

Results

Table 1 gives the mean proportion of trials on which the convex region was reported as figure for each condition. Subject means were submitted to a 2 X 2 analysis of variance (ANOVA). Neither the main effect of the Number of Regions nor Display Type was significant, but the interaction was, $F(1,19) = 14.39$, $p < .05$. Follow up T-tests confirmed that participants were more likely to report convex regions as figure for the 8-region than 2-region stimuli with continuous displays, $t(19) = 4.18$, $p < .05$. This observation is a replication of the base CCE observed by Peterson & Salvagio (2008). Notice, however, that it is quite small (going from 0.82 to 0.85; see the top row of **Table 1**).

In regards to differences between the discontinuous occluder and gap displays, observers were no less likely to report convex regions as figure when there was a gap in the display than when the gap was covered by an occluder, t(19) = 1.26, n.s. Since there was no distinction between these conditions, it was important to determine whether the CCE resembled a CCE in the continuous or discontinuous conditions. In other words, if the resulting CCE resembled the CCE seen in 3-region display or 8-region display. Comparisons between the continuous 8-region conditions and both discontinuous conditions were made first to examine potential disruptions in the CCE. It was found that observers were no less likely to report the convex regions as figure for occluded 8-region displays as for continuous 8-regions displays, t(19) = 0.23. This is consistent with the prediction of the hypothesis that the CCE depends on the completion of concave regions into a continuous surface behind the convex regions. However, observers were also no less likely to report convex regions as figure in the gap displays as the continuous 8-region displays, t(19) = 0.76. That is, the gap did not disrupt the CCE as predicted by that hypothesis.

Discussion

The aim of this study was to test the hypothesis that the CCE (Peterson & Salvagio, 2008) is caused by the completion of the concave regions as a continuous background behind the convex regions. The introduction of an occluder or a gap was implemented to affect the completion, and therefore the CCE. It was predicted that having an occluder would not disrupt the CCE and that having a gap would disrupt the CCE due to the different visual cues that these stimuli provide.

The study did replicate the CCE. Moreover, consistent with the hypothesis that the CCE is caused by the completion of concave regions into a continuous surface behind the convex regions, the 8-region displays that were disrupted by an occluder yielded just as large a CCE as unoccluded 8-region displays did. However, inconsistent with the hypothesis, the 8-region displays that were disrupted by a gap also ended up having similar CCE as the unoccluded 8-region displays. This means that the gap condition did not disrupt the CCE and this result was unexpected. By comparing the CCE of the occluder and gap conditions, there was no clear distinction between the CCE values (see bottom row of **Table 1**). Therefore, the results are inconclusive with regard to our hypothesis.

There were two main limitations to the study that future work can consider. One is that the replication of the CCE for the continuous display conditions was much smaller than that observed by Peterson and Salvagio (2008). Though there was an increase in the context effect going from the three-region figure-ground condition to the eight-region condition, it was a small increase. This may be because a within-subjects design was used in this study, whereas Peterson and Salvagio (2008) used a between-subjects design. It is not clear why this would lead to a smaller effect, but it is a signficant design difference. In future studies, a between-subjects design could be implemented and hopefully a larger CCE will emerge.

The second limitation to the current study was the failure of the gap to disrupt the CCE. This may have occurred because subjects could have perceptually completed these displays. Although the stimuli in the gap condition were discontinuous, they are still ambiguous. For example, participants may have used the alignment of the top and bottom edges of the stimuli to form a completed surface. This would be consistent with looking through two windows at surface behind (see **Figure 5d**). Potential solutions to this problem would involve changes to the display. For example, the two separated regions could be misaligned. Another strategy could be to place additional objects between figure-ground regions to give observers an increased sense of depth and separation.

Despite the inconclusive results from the study, they are encouraging. In particular, they offer some support that completion occurred in the context of the figure-ground stimuli. This contributes to our understanding of figure-ground segregation and how it affects the visual perception of the external world. Research is being done to further explore aspects of segregation, like the recent discovery of accentuation as a new principle of figure-ground segregation (Pinna, Reeves, Koenderink, van Doorn, & Deiana, 2018). As more is learned about how human perceive the world through figure-ground segregation, the application of this knowledge will aid in improving perception and improving the efficiency of visual tools in the environment.

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Pinna, B., Reeves, A., Koenderink, J., van Doorn, A., & Deiana, K. (2018). A new principle of figure-ground segregation: The accentuation. *Vision Research*, *143*, 9-25.

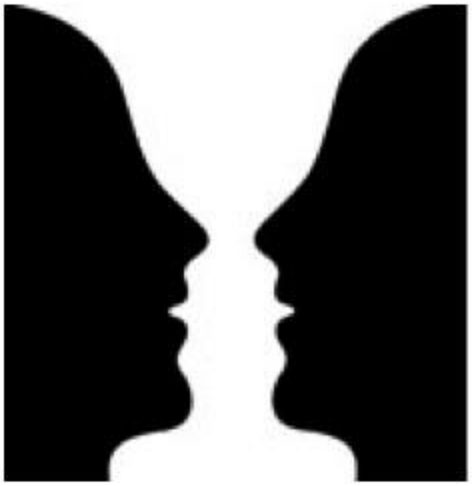

Figure 1 Face-vase image portraying figure-ground segregation.

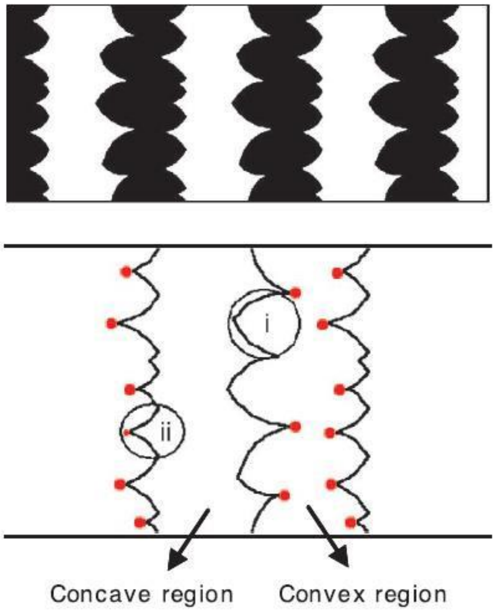

Figure 2 Depiction of figure-ground stimuli used in Peterson & Salvagio (2008) and the current study. The i is a convex edge, while ii is a concave edge. Depending on the edges that a region owns, the region will be labeled as a convex region (those with borders composed of i edges) or concave region (those with borders composed of ii edges).

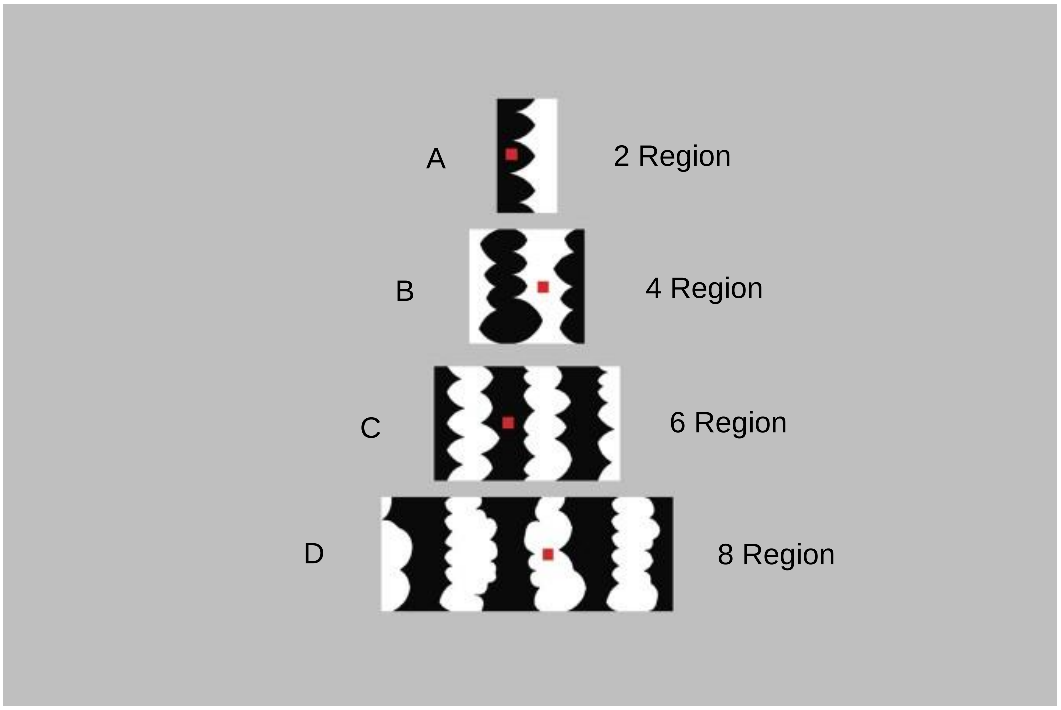

Figure 3 Figure-ground stimuli with varying number of regions; ranging from 2, 4, 6, and 8.

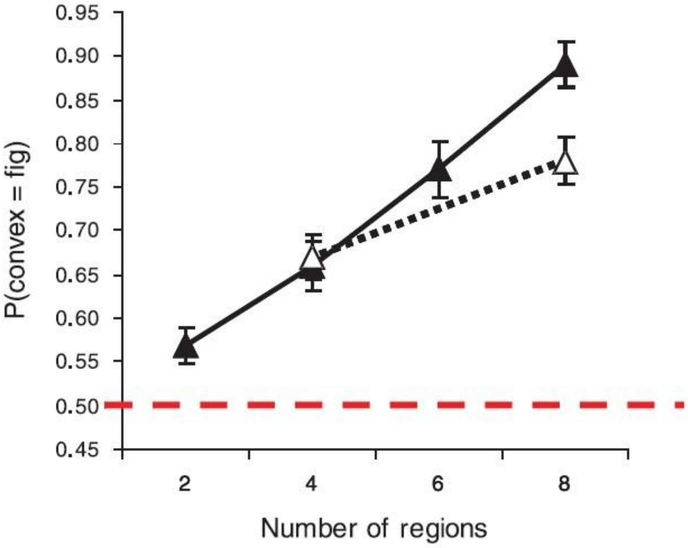

Figure 4 Peterson & Salvagio's (2008) observation of the Convexity Context Effect. Notice that as the number of regions increases, so does the bias for convex regions to be perceived as figure. The two functions are from two different sets of stimuli. The dotted function is from stimuli that had repeated, identical boundaries. The solid function is from stimuli that with unique boundaries.

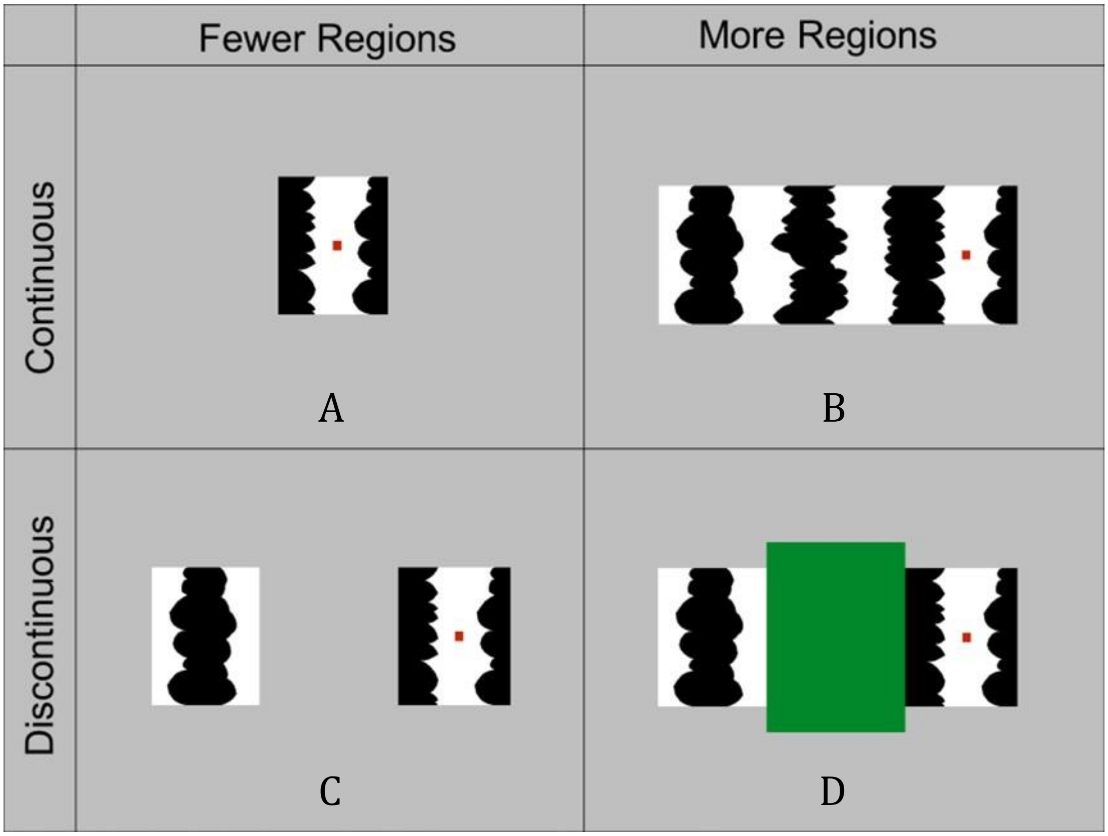

Figure 5 Table depicting the four conditions of the study. See text for details.

Table 1 The resulting convexity context effect or proportion of trials where participants perceived convex regions as figure for each of the four conditions. Each block corresponds to the conditions portrayed in **Figure 5**.

	Fewer Regions	**More Regions**
Continuous	.82 (.03)	.85 (.03)
Discontinuous	.85 (.03)	.85 (.029)