Research Article

Extremal Edges

A Powerful Cue to Depth Perception and Figure-Ground Organization

Stephen E. Palmer[1] **and Tandra Ghose**[2]

[1]*Psychology Department and* [2]*Vision Science Program, University of California, Berkeley*

ABSTRACT—***Extremal edges (EEs) are projections of viewpoint-specific horizons of self-occlusion on smooth convex surfaces. An ecological analysis of viewpoint constraints suggests that an EE surface is likely to be closer to the observer than the non-EE surface on the other side of the edge. In two experiments, one using shading gradients and the other using texture gradients, we demonstrated that EEs operate as strong cues to relative depth perception and figure-ground organization. Image regions with an EE along the shared border were overwhelmingly perceived as closer than either flat or equally convex surfaces without an EE along that border. A further demonstration suggests that EEs are more powerful than classical figure-ground cues, including even the joint effects of small size, convexity, and surroundedness.***

Observers often view natural scenes in which one opaque object partly occludes another so that their retinal projections share an image contour. Such situations raise a critical question for vision science: Which region attached to the shared edge is perceived as the closer, occluding "figure," and which region is perceived as the farther, partly occluded "ground"? The observer's choice of figure and ground determines not only perceived depth relations, but also the perceived shape of the closer surface, object-identification processes, and other shape-based processing.

Rubin (1921/1958) is well known for demonstrating several factors that bias perception toward seeing a given area as closer and figural. These factors include surroundedness, small size, higher contrast, and horizontal or vertical orientation. Since Rubin, researchers have identified many additional factors, including symmetry (Bahnsen, 1928), convexity (Kanizsa & Gerbino, 1976; Metzger, 1936/2006), familiarity (Peterson & Gibson, 1991, 1994), location in a lower region (Vecera, Vogel, & Woodman, 2002), wider base (Hulleman & Humphreys, 2004), and edge-region grouping (Palmer & Brooks, in press). The present article discusses another potent factor in figure-ground perception: extremal edges (EEs).[1]

An EE is the projection of a viewpoint-specific horizon of self-occlusion on a smooth convex surface. An EE for a given object from a specified viewpoint is defined as the projection of the subset of surface points whose sight lines from the viewpoint are tangent to the surface (e.g., Barrow & Tennenbaum, 1978; Malik, 1987).[2] Consider a person looking toward the side of a cylinder, as in the plan view shown in Figure 1a. Figures 1b and 1c illustrate the EE images that result if the cylinder's surface is homogeneous gray and black-and-white checkered, respectively. Figures 1d through 1f show plan views of the three qualitatively different depth relations that might hold between the EE and non-EE surfaces. Consistent with Helmholtz's (1867/1925) likelihood principle, an ecological analysis of viewpoint constraints suggests that the EE side is likely to be closer than the non-EE side because that possibility is consistent with a wider range of viewpoint locations (see also Huggins & Zucker, 2001a, 2001b). Situations in which the non-EE side is closer or touching the EE are highly accidental. Therefore, if the visual

Address correspondence to Stephen E. Palmer, Department of Psychology, University of California, Berkeley, Berkeley, CA 94720-1650, e-mail: palmer@cogsci.berkeley.edu.

[1]EEs have been used to produce figural biases, but we know of no prior systematic psychophysical studies of the effects of EEs on figure-ground organization. Shepard (1990, p. 72) used shading EEs in an ambiguous figure-ground drawing titled "Beckoning Balusters," and Diane Beck used them to bias the figural side of figure-ground displays in an unpublished study in our laboratory. Also, von der Heydt and Pierson (2006) discussed border ownership in asymmetrical luminance profiles in the watercolor illusion (Pinna, Brelstaff, & Spillmann, 2001) but did not explicitly discuss EEs.

[2]Zucker and his colleagues (Huggins, Chen, Belhumeur, & Zucker, 2001; Huggins & Zucker, 2001a, 2001b) have called EEs "folds," following the nomenclature developed in topology. This label seems to apply more naturally to situations in which gradient patterns define a depth edge between different regions of the same surface, such as folds of cloth in curtains or a full skirt. We prefer the EE terminology employed by Barrow and Tennenbaum (1978) in discussing figure-ground issues because it applies to cases in which the edge in question marks the bounding contour of the object on one side. Nevertheless, we acknowledge that what we mean by EEs is the same as what Zucker means by folds, and that EEs do not always correspond to object boundaries.

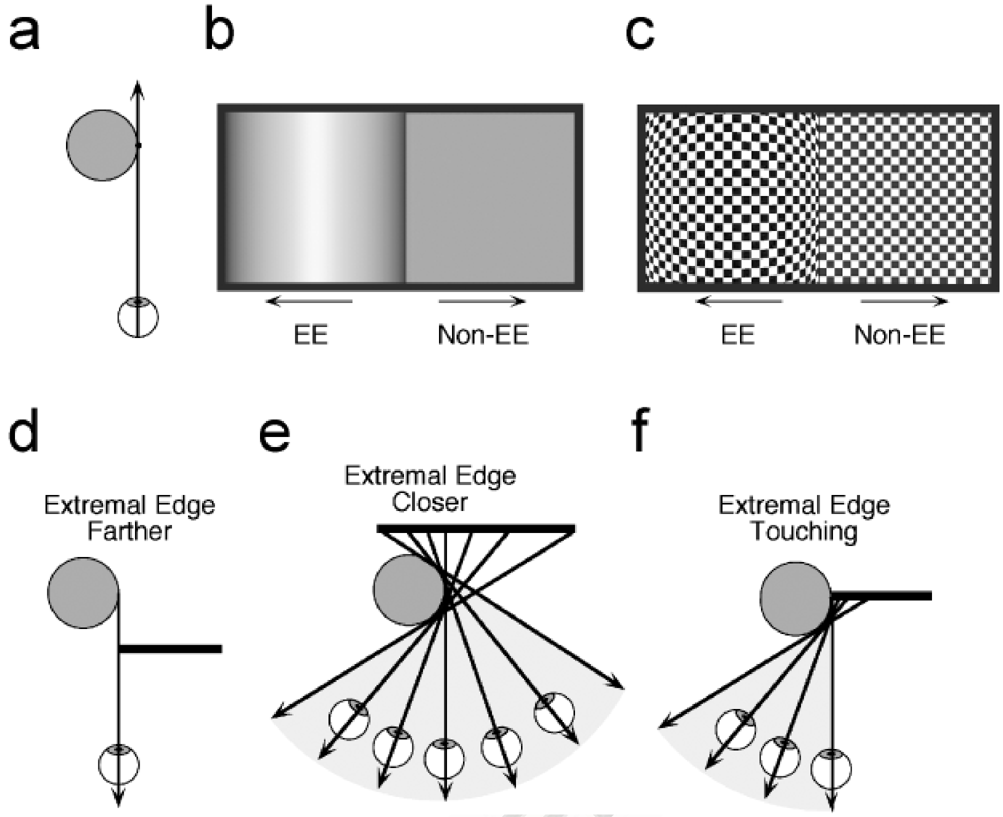

Fig. 1. An ecological analysis of extremal edges (EEs) based on general viewpoint. The illustrations in (b) and (c) show the EEs defined by a shading gradient and texture gradient, respectively, for an observer viewing a cylinder as shown in the plan view in (a); each EE is shown adjacent to a flat surface with the same surface properties. The plan views in the lower row illustrate that the EE side in these examples could be farther than (d), closer than (e), or touching (f) the non-EE side. The gray circles represent the cylinder as seen from above, and the solid line segments represent an adjacent flat surface at different depths. The shaded regions in (e) and (f) indicate the range of viewpoints from which the scene would project an EE image qualitatively like the ones in (b) and (c). If the non-EE surface is closer than the EE surface (d), moving rightward causes the flat surface to occlude the EE and moving leftward produces a gap. If the EE surface is closer than the non-EE surface (e), moving either way will preserve the EE along the shared contour. If the two surfaces touch (f), moving rightward reduces to the case shown in (d), and moving leftward reduces to the case shown in (e). The viewing area consistent with EE images is thus maximized if the EE side is closer than the non-EE side, and this implies that perception should favor this outcome.

system can distinguish EEs from non-EEs, it should tend to perceive the EE side as closer and figural.[3]

There is an important confound in Figures 1a and 1b, however. Because image regions bounded by an EE are, by definition, projections of convex 3-D surfaces, a preference to see them as closer might simply reflect a bias toward perceiving convex surfaces as closer. A bias toward seeing regions bounded by convex 2-D edges as closer and figural is well-known (Kanizsa & Gerbino, 1976; Metzger, 1936/2006), and a corresponding bias toward seeing convex 3-D surfaces as closer might be expected. Most environmental surfaces are at least locally convex, and in the absence of ecological statistics, the apparent flatness of canonical grounds (e.g., sky, ground planes, walls, and floors) lends intuitive weight to this argument.

The confound between depth convexity and the presence of EEs along shared contours can be eliminated, however, by studying cases in which the surfaces on the two sides of the critical edge are identical except for a 90° rotation that changes the placement of the EEs (see Fig. 2, upper left image). If the EE side is seen as closer, even when it is adjacent to an equally convex non-EE region, then mere convexity cannot explain the result.

[3]For clarity, we note that this is a different claim than is made in classical shape-from-shading or shape-from-texture analyses (e.g., Horn, 1975; Malik & Rosenholtz, 1994), which specify the relative distance to different points on a single surface on the basis of the optical structure of projected images independently of general viewpoint considerations. We also note, however, that the same considerations that apply to depth at EEs also apply to depth in a single complex-curved surface in which smooth self-occlusion occurs, such as in a fold of cloth. Zucker and his colleagues (e.g., Huggins et al., 2001; Huggins & Zucker, 2001a, 2001b) have investigated the image-based determinants of EEs in this latter context, referring to them as "folds" (on the EE side) and "cuts" (on the non-EE side). Finally, we note that other researchers have previously employed generic viewpoint arguments to explain other aspects of visual perception, such as stereoscopic depth (e.g., Koenderink & van Doorn, 1976), pictorial depth (e.g., Nakayama & Shimojo, 1992), shape from shading (e.g., Freeman, 1996), and figure-ground assignment (e.g., Palmer, 1999).

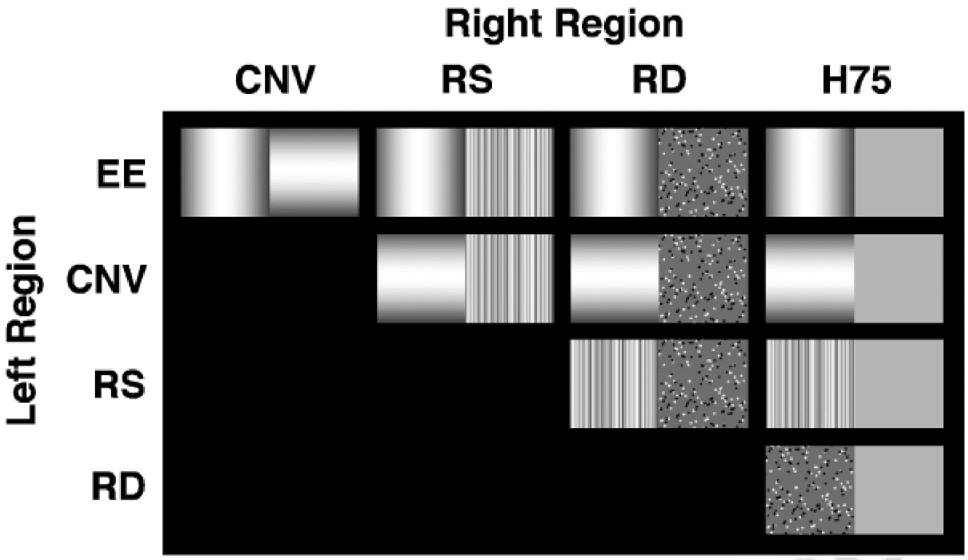

Fig. 2. Examples of the shading displays tested in Experiment 1. All nonidentical pairs of seven regions were used in horizontally oriented displays (shown) and vertically oriented displays (not shown): a convex region with an extremal edge along the shared edge (EE), an equally convex region with no extremal edge along the shared edge (CNV), a textured region consisting of randomized strips of the EE region (RS), a textured region that contained randomly positioned black and white random dots (RD), and uniform gray regions at 75% (H75), 50% (not shown), and 25% (not shown) of maximum luminance.

The two experiments we report here tested the influence of EEs on the perception of relative depth and figure-ground organization across a straight edge. Experiment 1 examined the perceptual effects of a simple luminance gradient (the positive half of a sinusoid) that produces the perception of a matte cylinder (see Fig. 1b). Experiment 2 examined perceptual effects using checkered texture gradients (see Fig. 1c). The results of both experiments strongly support the ecological predictions based on viewpoint constraints: EEs are a powerful factor in the perception of relative depth and figure-ground organization across a shared contour.

EXPERIMENT 1: EXTREMAL EDGES FROM SHADING GRADIENTS

Experiment 1 examined depth and figural perception for simple bipartite displays that consisted of a central, straight contour separating two equal-sized, square regions that were aligned vertically or horizontally. In the conditions of primary interest, one side contained an EE along the shared contour, and the other side did not. The EE side always consisted of a luminance gradient that was perpendicular to the central contour (i.e., a gradient whose equiluminance contours were parallel to the edge) and formed the positive half of a sinusoid (see Fig. 2, left regions in the top row).[4] We used three different kinds of luminance patterns as non-EE regions to control for possible confounds: homogeneous regions that controlled for differences in mean luminance, textured regions that controlled for 2-D contrast structure, and convex non-EE regions that controlled for 3-D convexity (see Fig. 2).

Method

Participants

Nine students at the University of California, Berkeley, volunteered to participate in exchange for partial course credit in an undergraduate psychology course. All had normal or corrected-to-normal vision

Apparatus

Displays were generated on a 15-in. Sony Vaio computer and presented on its LCD screen (size = 20.5 cm × 33 cm, resolution = 1280 × 800 pixels). Except for the displays on the screen, the room was dark. The observer's head was stabilized using a chin rest, and the screen was perpendicular to the line of sight. The size of the images, including a random-dot frame, was 10 cm × 16 cm (~10° × 16° at 57 cm). Presentation and response collection were controlled by a MATLAB program (Mathworks Ltd., Cambridge, United Kingdom) using routines from the Psychophysics Toolbox (Brainard, 1997).

Design

Simple bipartite displays were constructed using MATLAB. The two parts of each display were constructed by joining two square

[4]Note that although such surfaces might theoretically be concave rather than convex, concavity was virtually never perceived. Presumably, there is a strong perceptual bias toward perceiving convexity over concavity because of the ecological preponderance of convex surfaces in the natural environment.

regions (6.4 cm × 6.4 cm) along a horizontal edge in the vertically oriented displays and along a vertical edge in the horizontally oriented displays. The luminance pattern of each square region was one of the seven types (see Fig. 2): a convex region with an EE along the shared edge, an equally convex region with no EE along the shared edge, a textured region that consisted of randomized strips of the EE display, a textured region that contained randomly positioned black and white dots, and uniform gray regions at 75%, 50%, and 25% of maximum luminance. In both the horizontal and the vertical displays, we paired all possible nonidentical combinations, including versions that were left-right and up-down reflections. All pairs were surrounded by a rectangular random-noise field measuring 10 cm × 16 cm. The experiment had a fully within-subjects design in which each participant saw four replications of each display. Trials were blocked by display orientation (vertical vs. horizontal), but all other factors were randomly intermixed.

Procedure

The experiment was approved by the committee for the protection of human subjects at the University of California, Berkeley, and informed consent was obtained from all participants. Participants were instructed to press the appropriate key on a computer keyboard to indicate the side in each display that appeared closer. The response mappings were the natural ones: the left or right arrow key for horizontal displays and the up or down arrow key for vertical displays. Participants were given 10 practice trials followed by four blocks of experimental trials and were allowed to take a break after any trial.

Each trial began with the presentation of a 10-cm × 16-cm random-dot field containing a large fixation cross centered on a 50%-gray screen. The participant pressed a key to view the target display, which was then presented for 2 s. The target display was replaced by a random-dot field containing a large question mark, which prompted the participant to indicate which region appeared closer and figural. The question mark disappeared when the observer responded and was replaced by the random-dot field containing the large fixation cross, which indicated the start of the next trial.

Results and Discussion

We computed the percentage of trials on which participants chose the side with a given luminance pattern, for each other pattern with which it was combined. These data were averaged over the four replications and analyzed for positional effects. There was no bias toward left or right in the horizontal displays, $t(8) = 1.21$, $p > .20$, but the lower region was chosen more often than the upper region in the vertical displays (60% vs. 40%), $t(8) = 2.79$, $p < .05$), a finding consistent with the results of Vecera et al. (2002). We averaged these data to eliminate positional effects in subsequent analyses.

There were no significant differences between the results for the two kinds of textured regions (random strips and random dots) or among the results for the three uniform gray regions. We therefore averaged the data within each of these two categories. The major findings are easily summarized: EEs produced a very powerful bias toward seeing the EE side as closer and figural, $ts(8) = 8.00$, 5.82, and 8.01 for pairings with convex, textured, and uniform regions, respectively, $ps < .001$. There also appeared to be a weak effect of 3-D convexity on depth perception: Convex regions were seen as closer more often than were textured or uniform regions, but these effects barely approached significance, $ts(8) = 1.37$ and 1.73, $.05 < p < .10$, one-tailed. Texture also appeared to influence perceived depth, but the advantage for textured regions over uniform regions was only marginally reliable, $t(8) = 2.06$, $p < .05$, one-tailed.

The fact that EE regions were reliably seen as closer than the convexity-matched non-EE regions seems to indicate that EE effects are not attributable to convexity alone. One possible objection to this conclusion is that the shading gradient in the non-EE convex region appears to be occluded because of a *gradient cut* in which the central edge intersects the equiluminance contours of the gradient on the non-EE side. No gradient cut is present on the EE side of the central edge because the edge is parallel to the equiluminance contours of the EE gradient. The gradient cut on the non-EE side may therefore provide a depth cue indicating that the opposite (EE) side is closer and figural for reasons unrelated to the presence of an EE along the shared border.

In rebuttal, one could argue that the edges of the uniform and textured regions also produced gradient cuts when these regions were paired with convex regions. Thus, by the logic of the objection just mentioned, the uniform and textured regions should have been perceived as reliably closer than the convex regions. They were not. However, this rebuttal is open to the objection that the observed bias toward perceiving uniform and textured regions as farther could have been due to the effect of a gradient cut being countered by a bias toward seeing the convex side as closer because its convexity makes it appear to bulge toward the observer. To address the issue of whether gradient cuts in the non-EE regions could account for the pattern of results, we performed a stepwise regression analysis that predicted the data shown in Figure 3 from the difference between the left and right sides in a given display in terms of presence (vs. absence) of EEs, depth convexity, gradient cuts, and 2-D texture on the two sides. The order in which the variables were entered, additional percentage of variance accounted for, and corresponding F ratios were as follows—EE: 81%, $F(1, 10) = 41.62$, $p < .001$; depth convexity: 11%, $F(1, 9) = 11.82$, $p < .01$; and texture: 5%, $F(1, 8) = 11.24$, $p < .01$; no significant further variance was attributable to gradient cuts. This analysis yielded a multiple r of .98, accounting for 97% of the variance. Unfortunately, this result is not definitive because the presence versus absence of an EE along the shared edge is fully predictable from the

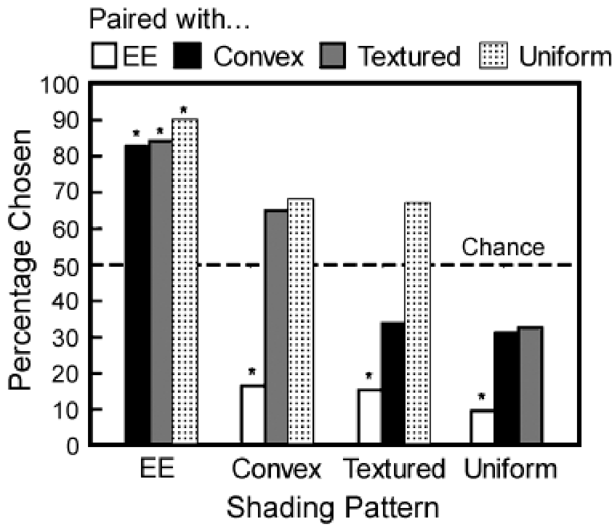

Fig. 3. Results of Experiment 1. Percentage of trials on which observers chose each region indicated along the abscissa when it was paired with each of the other regions (indicated by the shading of the bars). Data from the textured conditions (random strips and random dots) have been averaged, and data from the uniform gray conditions (75%, 50%, and 25% of maximum luminance) have been averaged. Asterisks indicate significant deviations from chance (i.e., the dashed line at 50%), $p < .001$. EE = region with an extremal edge.

combination of depth convexity and gradient cuts in this set of displays. We therefore revisited the issue of gradient cuts in Experiment 2, in which additional constraints were present.

Another argument against concluding that the EE along the central contour caused the large bias toward seeing the EE side as closer is that the EE side always contained a second EE along its far border. It is logically possible, although highly unlikely, that this second EE was somehow crucial in producing the bias toward seeing the EE side as closer in Experiment 1. Experiment 2 also addressed this issue.

EXPERIMENT 2: EXTREMAL EDGES FROM TEXTURE GRADIENTS

The ecological analysis of depth from EEs provided in Figure 1 concerns the relative distance of two surfaces that project to a shared depth edge, one side of which arises from a self-occluding convex surface and the other side of which does not. Because the general-viewpoint argument concerns only scene geometry and not the optical information that specifies the presence of EEs, the bias toward perceiving EE surfaces as closer should hold regardless of what visual property specifies the EEs. Therefore, in Experiment 2, we explored depth and figural perception when EEs were rendered by texture gradients. Our primary motivation was to determine whether texture also produces a strong bias toward perceiving EE regions as closer.

Using POVRAY software (freeware available at www.povray.org), we constructed ray-traced images of surfaces defined by checkered textures. The five surface types are illustrated in Figure 4 along with a single example of a display formed when two such regions are joined along the shared edge. To ensure that size cues did not favor the EE region, we made the square checks on the flat regions the same size as the largest checks on the EE and convex regions, and thus substantially larger than the smaller checks along the EEs. To minimize any occlusion cues to depth, we aligned the texture elements along the central contour so that the edges of the individual texture elements of the non-EE region fell along the straight line of the contour and there was no partial occlusion of texture elements. We included quarter-cylinder regions that contained a single EE (i.e., along the shared contour) so that we could examine possible effects of the second EE in the half-cylinder conditions of Experiment 1. The experimental question was whether, as predicted by the ecological analysis, the EE regions in both the quarter-cylinder and the half-cylinder textured displays used in Experiment 2 would be reliably seen as figural and closer than the corresponding non-EE convex regions, as well as the flat regions.

Method

Participants
Eight students at the University of California, Berkeley, participated in exchange for partial course credit in an undergraduate psychology course. All had normal or corrected-to-normal vision

Apparatus
The displays were presented on the same Sony Vaio computer under the same conditions as in Experiment 1.

Design
We used POVRAY, an open-source ray-tracing program, to construct displays similar to those in Experiment 1, but with the surfaces rendered using texture instead of shading. By cropping along the median plane, we eliminated partly occluded square texture elements along the shared contour, thus ensuring that occlusion was not a factor in depth perception across the edge (see Fig. 4). We used four different checkerboard patterns: red-black, green-black, white-black, and white-gray (the gray was 10% of maximum luminance). In these bipartite displays, red-black and green-black regions were paired, as were white-black and white-gray regions. Within this constraint, we paired all possible nonidentical combinations, including versions that were left-right reversals and check-pattern reversals (i.e., displays in which the color or the contrast of the checks was reversed in the left and right images). The pairs were displayed on a uniform 50%-gray background. The experiment had a fully within-subjects design, in which each participant was presented with three replications of each of the displays.

Procedure
The experiment was approved by the committee for the protection of human subjects at the University of California, Berkeley, and informed consent was obtained from all participants. Par-

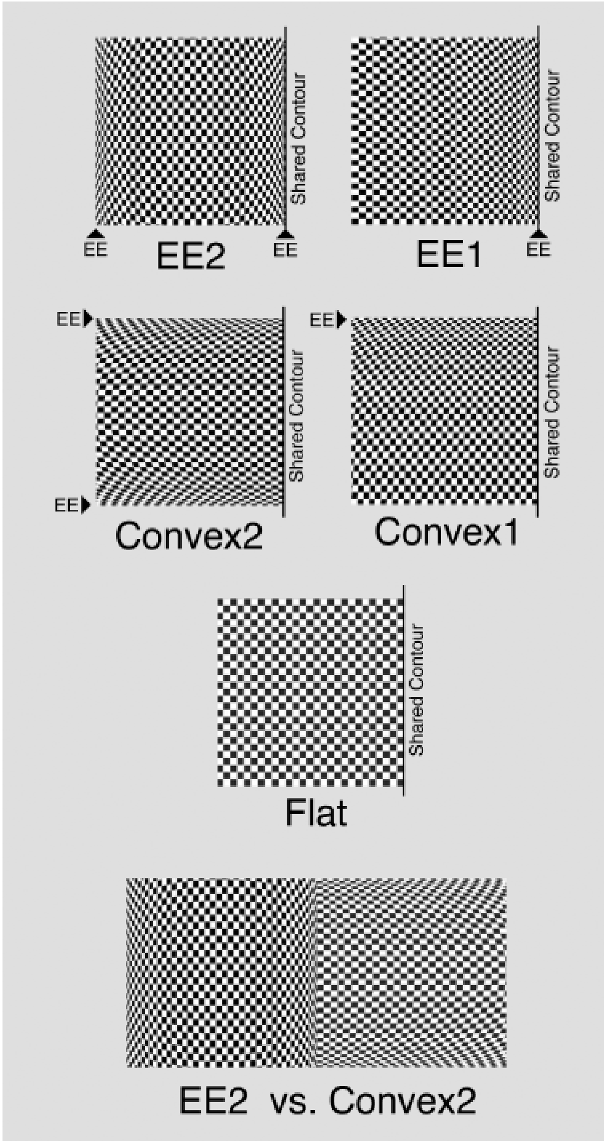

Fig. 4. Textured regions used in Experiment 2 and a sample display. All nonidentical pairings of five checkered regions were used: a half-cylinder with two extremal edges (EEs), one of which was along the shared border (EE2); a quarter-cylinder with one EE along the shared border (EE1); a half-cylinder with two EEs, neither of which was along the shared border (Convex2); a quarter-cylinder with one EE not along the shared border (Convex1); and a flat surface perpendicular to the line of sight (Flat). The bottom display shows the EE2-Convex2 pairing, in which the two sides were identical except for a 90° rotation in the picture plane.

ticipants received the same instructions as in Experiment 1, and the sequence of events on each trial was also the same.

Results and Discussion

Figure 5 presents the percentage of trials on which each region was chosen as the closer, figural region, averaged over positions (left vs. right), colors (red vs. green), and contrast (high vs. low). The bias toward seeing the EE regions as closer than the flat regions was overwhelming, with the half-cylinder and quarter-cylinder EE regions (EE2 and EE1, respectively) being seen as closer on 96% and 90% of the trials, respectively, $ts(7) = 16.15$ and 5.56, $ps < .001$. The bias toward perceiving the half-cylinder EE regions (EE2) as closer than the non-EE convex regions was equally powerful, with the former regions being seen as closer on 95% of trials when the non-EE region was a half-cylinder (Convex2) and 96% of trials when the non-EE region was a quarter-cylinder (Convex1), $ts(8) = 15.94$ and 14.55, $ps < .001$, respectively. The quarter-cylinder EE regions (EE1) were also seen as closer than the rotated convex versions on 85% of the trials with half-cylinder non-EE regions (Convex2) and 90% of the trials with quarter-cylinder non-EE regions (Convex1), $ts(7) = 4.45$ and 6.13, $ps < .001$, respectively. There was a reliable bias toward seeing the half-cylinder EE regions (EE2) as closer than the quarter-cylinder EE regions (EE1), $t(7) = 8.52$, $p < .001$. Because both sides contained an EE along the shared contour in this condition, this bias may reflect either the presence of the second EE in the half-cylinder EE regions or the fact that the surface curvature was greater in the half-cylinder than in the quarter-cylinder EE region. Further research is needed to determine the cause of this bias.

As in Experiment 1, there was a small bias toward seeing the half-cylinder non-EE regions (Convex2) as closer than the flat regions (57%), but the effect was not statistically reliable, $t(7) = 0.69$, $p > .50$. The quarter-cylinder non-EE regions (Convex1) produced a trend that was, if anything, in the opposite direction (42%), but also was not significant, $t(7) = 0.83$, $p > .40$. Thus, we found no clear evidence that curvature, by itself, is a cue to depth and figural status in textured displays. We note, however, that texture size actually opposed curvature in this experiment because the size gradient along the shared edge made the texture elements on the EE side a good deal smaller than those on the flat side.

We performed a stepwise multiple regression analysis to predict the data shown in Figure 5 from presence versus absence of (a) an EE on the closer, shared edge (EE-close); (b) an EE on the far edge (EE-far); (c) an EE orthogonal to the edge (EE-ortho), (d) depth convexity, and (e) a gradient cut. EE-close was entered first and accounted for 92% of the variance, $F(1, 23) = 263.40$, $p < .001$. EE-far was entered next and accounted for 4% of additional variance, $F(1, 22) = 22.98$, $p < .001$. With just these two variables, the model had a multiple r of .98 and accounted for 96% of the variance. The other variables did not reach the criterion for entry into the regression equation ($p < .05$), and when we forced the gradient-cut variable into the equation with EE-close and EE-far, the multiple regression program removed it. Thus, gradient cuts do not appear to be an important factor in the results of this experiment; all of the predictable variance was associated with the presence versus absence of an EE along the shared contour (EE-close) or on the far side (EE-far). These results leave little doubt that the primary bias toward perceiving the EE side as closer and figural was, in fact, due to the presence of EEs along the central shared contour.

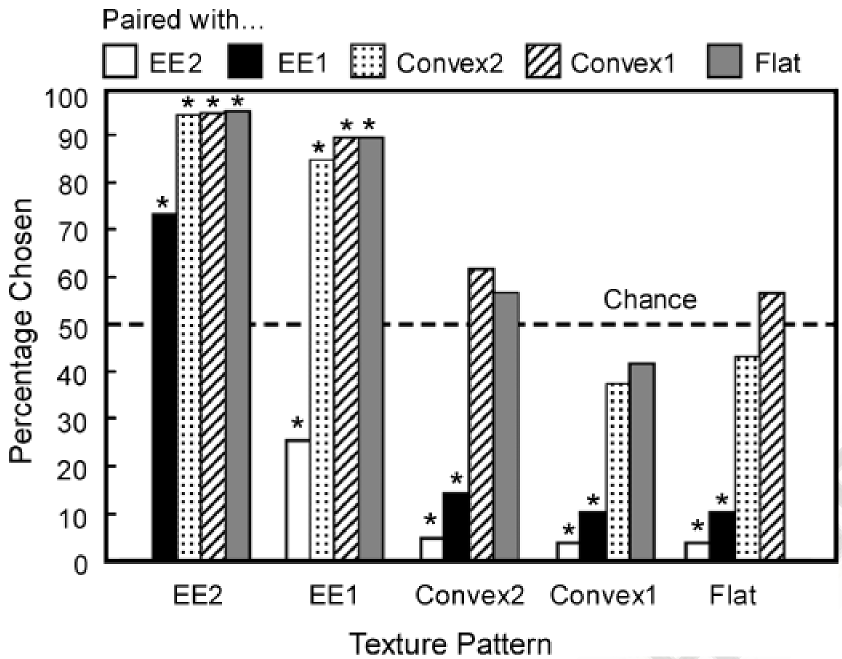

Fig. 5. Results of Experiment 2. Percentage of trials on which observers chose each region indicated along the abscissa when it was paired with each of the other regions (indicated by the shading of the bars). See Figure 4 for an explanation of the labels of the regions. Asterisks indicate percentages that deviated significantly from chance (i.e., the dashed line at 50%), $p < .001$.

CONCLUSION

A viewpoint-based ecological analysis of the depth implications of EEs implies that when there is an EE on one side of the shared contour, the EE region is more likely than the non-EE region to be closer to the observer. We tested this prediction by having human observers report their perception of depth and figural status in EE displays rendered by shading gradients and texture gradients. Both factors strongly biased observers to perceive the EE side as closer and figural. Indeed, subsequent results from our laboratory (Palmer & Ghose, 2006) show that EEs are powerful enough to dominate even the combination of surroundedness, small size, and convexity, three of the classical factors that most strongly bias perception of a region as figural (see Fig. 6). The present findings thus demonstrate that human perception conforms to ecological predictions based on general viewpoint considerations: Regions with an EE along the shared edge are highly likely to be perceived as closer to the observer than the regions on the other side of the edge.

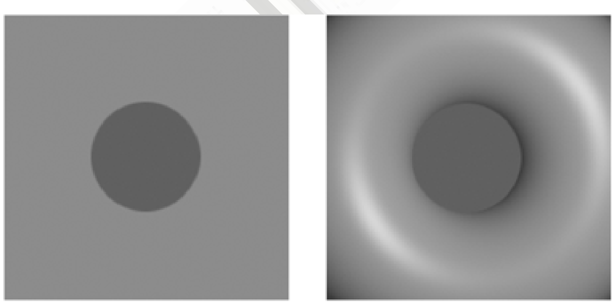

Fig. 6. Demonstration that extremal edges (EEs) can dominate classical figure-ground cues. In the illustration on the left, the combination of small size, convexity, and surroundedness strongly biases perception toward seeing the darker central circle as closer and figural. However, in the illustration on the right, the addition of an exterior EE defined by shading and highlights easily overpowers these otherwise potent classical figure-ground cues.

REFERENCES

Bahnsen, P. (1928). Eine Untersuchung über Symmetrie und Asymmetrie bei visuellen Wahrnehmungen. *Zeitschrift für Psychologie*, *108*, 129–154.

Barrow, H.G., & Tennenbaum, J.M. (1978). Recovering intrinsic scene characteristics from images. In A. Hanson & E. Riseman (Eds.), *Computer vision systems* (pp. 3–26). New York: Academic Press.

Brainard, D.H. (1997). The Psychophysics Toolbox. *Spatial Vision*, *10*, 433–436.

Freeman, W.T. (1996). Exploiting the generic viewpoint assumption. *International Journal of Computer Vision*, *20*, 243–261.

Helmholtz, H.von. (1925). Treatise on physiological optics (3rd ed., Vol. 3; J.P.C. Southall, Trans.). New York: Optical Society of America. (Original work published 1867)

Horn, B.K.P. (1975). Obtaining shape from shading information. In P.H. Winston (Ed.), *The psychology of computer vision* (pp. 115–155). New York: McGraw-Hill.

Huggins, P.S., Chen, H.F., Belhumeur, P.N., & Zucker, S.W. (2001). Finding folds: On the appearance and identification of occlusion. In *Proceedings of the 2001 IEEE Computer Society Conference on Computer Vision and Pattern Recognition* (Vol. 2, pp. 718–725). Los Alamitos, CA: IEEE Computer Society.

Huggins, P.S., & Zucker, S.W. (2001a). Folds and cuts: How shading flows intoedges. In *Proceedings, Eighth IEEE International Conference on Computer Vision* (Vol. II, pp. 153–158). Los Alamitos, CA: IEEE Computer Society.

Huggins, P.S., & Zucker, S.W. (2001b). How folds cut a scene. In C. Arcelli, L.P. Cordella, & G. Sanniti de Baja (Eds.), *Visual Form 2001: 4th International Workshop on Visual Form* (pp. 323–332). Berlin: Springer.

Hulleman, J., & Humphreys, G.W. (2004). A new cue to figure-ground coding: Top-bottom polarity. *Vision Research*, *44*, 2779–2791.

Kanizsa, G., & Gerbino, W. (1976). Convexity and symmetry in figure-ground organization. In M. Henle (Ed.), *Vision and artifact* (pp. 25–32). New York: Springer.

Koenderink, J.J., & van Doorn, A.J. (1976). Geometry of binocular vision and a model for stereopsis. *Biological Cybernetics*, *24*, 51.

Malik, J. (1987). Interpreting line drawings of curved objects. *International Journal of Computer Vision*, *1*, 73–103.

Malik, J., & Rosenholtz, R. (1994). Recovering surface curvature and orientation from texture distortion: A least squares algorithm and sensitivity analysis. In *Proceedings of the Third European Conference on Computer Vision* (pp. 353–364). New York: Springer-Verlag.

Metzger, W. (2006). *The laws of seeing* (L. Spillmann, Trans.). Cambridge, MA: MIT Press. (Original work published 1936)

Nakayama, K., & Shimojo, S. (1992). Experiencing and perceiving visual surfaces. *Science*, *257*, 1357–1363.

Palmer, S.E. (1999). *Vision science: Photons to phenomenology*. Cambridge, MA: MIT Press.

Palmer, S.E., & Brooks, J.L. (in press). Edge-region grouping in figure-ground organization and depth perception. *Journal of Experimental Psychology: Human Perception and Performance*.

Palmer, S.E., & Ghose, T. (2006, May). *Extremal edges dominate other cues to figure-ground and depth perception*. Paper presented at the annual meeting of the Vision Science Society, Sarasota, FL.

Peterson, M.A., & Gibson, B.S. (1991). The initial identification of figure-ground relationships: Contributions from shape recognition processes. *Bulletin of the Psychonomic Society*, *29*, 199–202.

Peterson, M.A., & Gibson, B.S. (1994). Must figure-ground organization precede object recognition? An assumption in peril. *Psychological Science*, *5*, 253–259.

Pinna, B., Brelstaff, G., & Spillmann, L. (2001). Surface color from boundaries: A new 'watercolor' illusion. *Vision Research*, *41*, 2669–2676.

Rubin, E. (1958). Figure and ground. In D.C. Beardslee & M. Wertheimer (Eds.), *Readings in perception* (pp. 194–203). Princeton, NJ: Van Nostrand. (Original work published 1921)

Shepard, R.N. (1990). *Mind sights: Original visual illusions, ambiguities, and other anomalies, with a commentary on the play of mind in perception and art*. San Francisco: Freeman.

Vecera, S.P., Vogel, E.K., & Woodman, G.F. (2002). Lower region: A new cue for figure-ground assignment. *Journal of Experimental Psychology: General*, *131*, 194–205.

von der Heydt, R., & Pierson, R. (2006). Dissociation of color and figure-ground effects in the watercolor illusion. *Spatial Vision*, *19*, 323–340.

(Received 4/7/07; Revision Accepted 6/25/07)

Author Query Form

Journal	**PSCI**
Article	**2049**

Dear Author,

During the copy-editing of your paper, the following queries arose. Please respond to these by marking up your proofs with the necessary changes/additions. Please write your answers clearly on the query sheet if there is insufficient space on the page proofs. If returning the proof by fax do not write too close to the paper's edge. Please remember that illegible mark-ups may delay publication.

Query No.	Description	Author Response
.	No Queries	