Figure–ground assignment to a translating contour: A preference for advancing vs. receding motion

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Past research on figure–ground assignment to contours has largely considered static stimuli. Here we report a simple and extremely robust dynamic cue to figural assignment, based on whether the bounding region of a contour is growing larger within the field of view ("advancing") rather than smaller ("receding"). Subjects viewed a straight or jagged contour dividing two colored regions translating behind a virtual aperture and had to report which color they had seen "moving in front", effectively assigning figure to that side of the contour. Across three experiments, subjects showed a strong preference to assign figure such that the bounded contour was advancing. This was true regardless of the direction of motion of the contour and regardless of the initial/ending size of the bounded regions (i.e., the motion cue served to override the conventional cue to figure–ground of smaller area). In a fourth, control experiment, subjects showed no such bias when it was the aperture, rather than the contour, that moved, demonstrating that the effect depends on contour motion and not simply an increase in area. We discuss a possible explanation for this bias as well as the general implications regarding dynamic factors in form perception.

Keywords: motion—2D, perceptual organization, shape and contour, figure–ground

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Introduction

Figure–ground assignment is a basic step in visual processing, determining the depth ordering of surfaces, as well as the sign of curvature (i.e., positive/convex or negative/concave) of contour regions. The problem of figure–ground assignment is among the oldest in the study of vision, and over the years, researchers have identified a large number of cues known to influence figural assignment. These include *size* (smaller areas assigned to figure; Koffka, 1935; Rubin, 1921), *symmetry* (Bahnsen, 1928; Kanizsa & Gerbino, 1976), *convexity* (Kanizsa & Gerbino, 1976; Koffka, 1935; Stevens & Brookes, 1988), *lower region* (Vecera, Vogel, & Woodman, 2002), and *familiarity* (Peterson & Gibson, 1993, 1994). Studies of figural assignment have typically only considered stationary images containing static contours. As such they have overlooked a potentially rich source of information concerning figural assignment: the dynamic properties of moving contours. More specifically, objects in the natural world typically generate a dynamic image on the retina due to their own motion or that of the observer, and the motion of the occluding contour may provide additional constraints on figure–ground assignment that are not present in any static view.

Supporting this argument, there are several reports in which the properties of stimulus features *surrounding* a moving contour drive figure–ground assignment. For example, in "Kinetic Occlusion", one texture moves laterally, toward, or away from a stationary flanking texture (Gibson, Kaplan, Reynolds, & Wheeler, 1969; Kaplan, 1969). The resulting percept is of a moving surface with an illusory contour, sliding *in front* of another stationary surface behind it, that is, occluding ("deleting") or revealing ("accreting") the background surface's texture elements. It has been proposed that this effect is due to the accretion or deletion of texture elements, which always signifies that the textured surface is "behind" a moving foreground surface that is occluding it (Gibson et al., 1969). A related phenomenon is the "Screening Effect" (Michotte, Thines, & Crabbe, 1964) in which a shape (e.g., a white circle) appears on a uniform background (such as a black screen). Over progressive frames, the shape disappears as the uniform background encroaches on it, leading to a perceptual experience of an occluding surface covering the shape. Similar to accretion/deletion of texture, Michotte et al. (1964) proposed that the disappearing shape is viewed as a permanent static background being occluded by a foreground surface. However, Yonas, Craton, and Thompson (1987) have argued that both Kinetic Occlusion and the screening effect may instead

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depend on *grouping* between the occluding contour and the adjacent texture elements. They found that Kinetic Occlusion is perceived even when no texture elements are accreted or deleted, as long as there is common motion between the texture elements and a translating boundary. In more recent studies, Palmer and Brooks (2008) and Palmer, Brooks, and Nelson (2003) found that similarity between texture elements and a visible moving contour along a number of dimensions (not just common motion) is sufficient to produce a strong figure–ground bias to the contour, a phenomenon they refer to as "Edge-Region Grouping" or ERG (Palmer & Brooks, 2008).

While these earlier studies demonstrate that motion (or at least relative motion) can influence figure–ground, they all involve an interaction between a contour (whether real or illusory) and neighboring texture or shape features. However, more recent studies suggest that the motion properties of a contour alone can induce a figural assignment, even in the absence of neighboring texture. In a series of experiments using dynamically deforming contours, Barenholtz and Feldman (2006) found that subjects have a bias toward assigning figure so that an *articulating* vertex (i.e., in which one of the two edges forming an angle rotated at the vertex) had negative curvature. Critically, this bias appears to reflect the typical motion of many biological articulations, in which rigid parts articulate at concave part boundaries (Barenholtz & Tarr, 2008). More pertinent to our current study, such findings demonstrate that dynamic properties of a contour alone—even in the absence of adjacent texture—can drive a figural assignment in the absence of, or even in opposition to, established static cues to figure–ground.

Advancing vs. receding

Here we investigate the assignment of figure and ground to a contour undergoing one of the simplest forms of motion: *translation*. Across three experiments, we find that subjects show a consistent bias for reporting figural assignment such that the figure bound by a translating contour is in the *opposite* direction of the translational motion. That is, subjects tend to see the "object" bound by the contour as expanding or "advancing" rather than contracting or "receding", within the field of view (Figure 1). A contour that divides two colored regions introduces a figure–ground ambiguity; the central region in the left panel of Figure 1 can be seen as a black figure on a white background or a white figure on a black background. When translational motion is introduced as in the center panel of Figure 1b, a black-as-figure interpretation would correspond to an object that is "advancing" within the field of view gradually occluding more of the background, while a white-as-figure interpretation would correspond to an object that is "receding" within the field of view, gradually revealing more of the background. As described here, across a variety of experimental conditions we find a consistent bias to assign figure so that the object is advancing rather than receding.

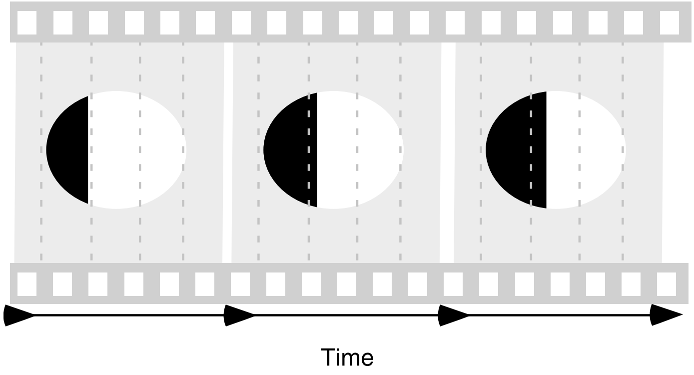

Figure 1. Illustration of stimuli used in Experiment 1. A straight border separating two different regions as viewed through a virtual "aperture" is translated over time. Depending on figure–ground assignment, this can be interpreted as a black surface "advancing" in front of a white background or a white surface "receding" in front of a black background. Note that gray dashed gridlines are for illustration purposes only and did not appear in the actual experimental stimuli. For an animated version, see Movie file "Exp 1.gif" 1 in the Supplementary materials.

Although the stimuli used in this experiment bear superficial similarity to those in earlier studies of dynamic figure–ground assignment, such as Kinetic Occlusion, the lack of texture in our displays is a critical distinction. Unlike earlier experiments in which the bias could be explained by appealing to a "real-world" regularity, such as the accretion or deletion or texture elements in background surfaces or grouping within objects, the underlying explanation behind the bias described here is not obvious: assuming a generic viewpoint, a rigid object translating in space (or a stationary object in a translating visual field due to observer motion) will produce advancing and receding visual images with equal probability (Figure 2). A possible explanation for the bias we observe is presented in the General discussion section.

With the exception of Experiment 4, the same paradigm was used for all of our experiments. Subjects viewed a contour that formed the boundary between two uniformly colored regions translating behind a virtual "aperture" (in Experiment 4, the aperture itself translated). Perceptually, this motion is experienced as one figural region being "in front", that is, sliding over a stationary background region. The subjects' task was simply to decide *which* color they perceived as being "in front" of the other.

Experiment 1

Methods

Subjects

Fifteen Brown University undergraduate students participated in the experiment for pay. All provided written,

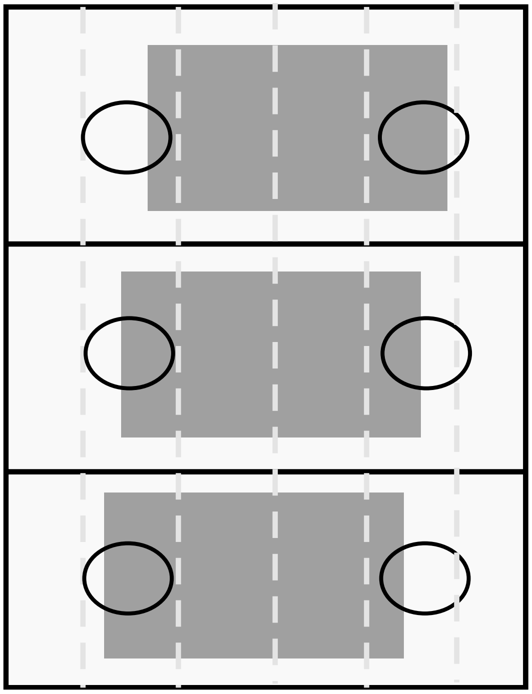

Figure 2. Three panels, representing time slices of a translating rectangular object, observed from different “viewpoints” (black circles). The same translation produces advancing motion for the “head” viewpoint (i.e., the border that is on the same side as the direction of motion) and receding motion for the “tail” viewpoint.

informed consent as approved by the Brown University IRB.

Stimuli

Stimuli were computer-generated animation sequences consisting of two, differently colored regions (the color of each region was randomly chosen on each trial)[1] separated by a straight boundary with a random orientation. This central display, which measured approximately 2.5 visual degrees in diameter, was viewed through an on-screen virtual “aperture” (Figure 1) displayed on an otherwise gray screen. During the animation sequence, the border dividing the two colored regions moved orthogonally to the orientation of the border. This had the effect of increasing the size of one colored region (“advancing”) and decreasing the size of the other (“receding”). On each trial, the contour moved 15% of the total aperture diameter (approximately 3 degrees visual angle) during a 700-ms interval. The proportional start/end size (i.e., at the beginning and at the end of the motion sequence) of the advancing region was varied across trials, including an equal number of cases where the advancing region constituted 20/35% (starting/ending), 40/55%, and 70/85% of the aperture area. This allowed us to determine whether there was any main effect for the size of the overall area—in that smaller area is a well-known cue to figure and ground—or whether there was an interaction between size and motion type (i.e., advancing or receding).

Procedure

Before participating, each subject read instructions stating that they would be viewing colored regions in motion and that their task was to remember, after a brief delay, which color had been “moving in front” during the motion display. On each trial, the subject viewed a fixation cross for 500 ms, followed by the motion sequence described above (700 ms), finally followed by a gray screen for 1 s. Afterward, a test screen appeared in which two square color patches, corresponding to the two colors present in the stimulus sequence, were presented to the right and left (randomly assigned) of the screen. The subject was instructed to choose which color was the one that they had perceived as “moving in front” during the motion sequence. Each subject performed a total of 96 trials (32 trials of the three start/end size conditions).

Results

We calculated the percentage of trials on which subject responses were consistent with a figural assignment in which the “moving” region was advancing or receding. The mean across all 15 subjects was 75% in favor of advancing (SE = 0.05). This preference was significant by t-test ($t(14) = 4.14$, $p < 0.001$). Broken down by subject, 12 subjects showed a statistically significant bias for advancing with a mean of 85%, two subjects showed no consistent preference and one subject showed a preference in the opposite direction (26% “advancing” responses). An ANOVA comparing the percentage of trials on which respondents chose advancing across the three start/end conditions found no significant differences ($F(2, 13) = 2.235$, $p > 0.05$).

Discussion

These results demonstrate a bias to assign figure to a translating straight contour such that the object defined by the figural assignment is advancing rather than receding. The absence of any effect of relative size on this preference, despite the fact that there is typically a perceptual bias to see the smaller region as figure, suggests that this dynamic cue can serve to “override” a non-dynamic cue, a phenomenon also observed in earlier studies of dynamic figure–ground assignment (Barenholtz & Feldman, 2006).

There are a number of possible ways to characterize this basic effect. One fundamental ambiguity is whether the effect is due to an interpretation of an object looming in

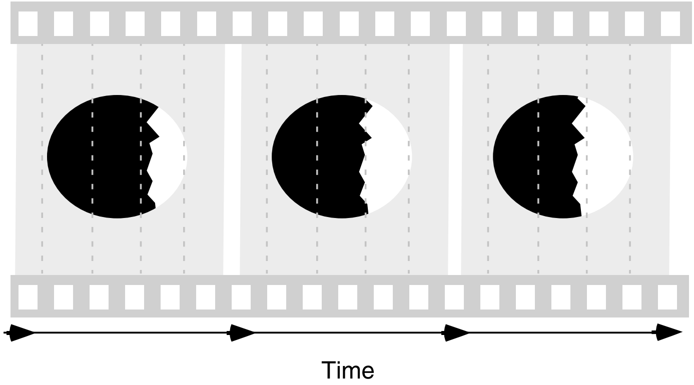

Figure 3. Illustration of stimuli used in Experiment 2 using a "jagged" contour, in which the direction of motion of the dividing contour is unambiguous. Here the white region is "advancing". For an animated version, see Movie file "Exp 2.gif" 1 in the Supplementary materials.

depth. That is, because of the "aperture problem" (Adelson & Movshon, 1982; Nakayama & Silverman, 1988), a region increasing in size as in this experiment might be interpreted as approaching in depth—since objects approaching in depth increase their apparent size—while one that is growing smaller in size may be viewed as retreating in depth. Perhaps the preference observed here is a preference for objects "looming" in depth rather than "retreating" in depth, not a preference for planar translational motion. (It should be noted that like translational "advancing", looming in depth does not seem to hold any *a priori* advantage over retreating and thus the actual source of bias for one figure–ground interpretation over the other would still be unexplained under this interpretation.)

Experiment 2

To test the possibility that the bias observed in Experiment 1 was actually a preference for a looming-in-depth interpretation of the figural region, Experiment 2 used translating contours with multiple vertices to form a jagged polygonal shape (Figure 3). The presence of these geometric landmarks on the contours eliminates the aperture problem because if the visible motion is actually due to a change in depth then it would be accompanied by a vertical component that would be highly evident at the borders of the annulus. Thus, the motion is an unambiguous two-dimensional translation of a surface without any significant change in depth. If the advancing bias observed in Experiment 1 persists under these conditions, then it is unlikely to be attributable to a preference for approaching motion.

Methods

Subjects

Fifteen Brown University undergraduate students who did not participate in any of the earlier experiments participated in the experiment for pay. All provided written, informed consent as approved by the Brown University IRB.

Stimuli and procedure

The stimulus and task were similar to those used in Experiment 1 with the exception that the contour bounding the two colored regions consisted of between 25 and 30 connected vertices. Each of the vertices was randomly offset from the center of the line connecting the endpoints by between 2% and 5% of the size of the aperture window (Figure 3).

Results

We again calculated the percentage of trials on which subject responses were consistent with a figural assignment in which the "moving" region was advancing or receding. The mean across all 15 subjects was 82% in favor of advancing ($SE = 0.06$). This preference was significant by *t*-test ($t(14) = 4.65$, $p < 0.001$). Broken down by subject, 13 subjects showed a statistically significant bias for advancing with a mean of 87%, and two subjects showed no preference. No effect or interaction for relative size was observed.

Discussion

As in Experiment 1, a strong bias for assigning figure in the opposite direction of motion was observed. Based on these results, we can reject the possibility that the observed preference is due to a "looming-in-depth" interpretation of the motion. That is, the preference holds under conditions even where the contour motion consists of an unambiguous two-dimensional translation.

Experiment 3

While the bias observed in Experiment 2 cannot be due to a preference for "looming" in depth, the nature of the jagged contour used in the experiment raises an alternative possibility. While the assignment of figure–ground is typically associated with the depth ordering of surfaces, assigning figure and ground to a contour may also be characterized in terms of determining the sign of curvature at each point along the surface. As demonstrated in Barenholtz and Feldman (2006), this aspect of figural

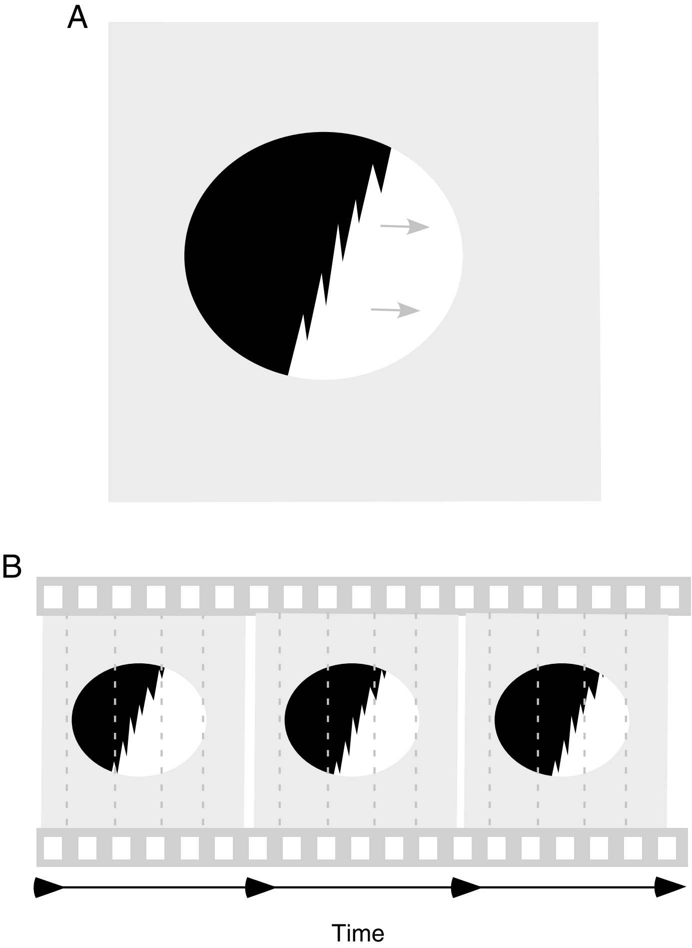

Figure 4. Stimuli from Experiment 3. (A) The stimulus contained a dividing contour composed of a "sawtooth pattern" in which the axis of each "tooth" was parallel to the larger contour. Motion was orthogonal to the main axis of each "tooth". See text for details of construction. (B) An illustration of a motion sequence. For an animated version, see Movie file "Exp 3.gif" 1 in the Supplementary materials.

assignment can be critical in driving subjective figure–ground assignment to moving stimuli. Perhaps a similar principle is at work in the stimuli used in Experiment 2; the bias may be to assign figure such that the convexities are seen as pointing in the direction of the motion rather than the opposite direction. That is, in the stimuli used in Experiment 2, the "advancing" of the contour and the pointing of the convexities are confounded. To address this, Experiment 3 used jagged contours (which maintain the advantage of resolving the aperture problem) that are constructed so as to not "point" in the direction of the motion regardless of figure–ground assignment. More specifically, the moving contours that divided the two colored regions consisted of a "sawtooth" pattern in which the main axis of each "tooth" (i.e., its pointing direction) was perpendicular to the motion of the contour itself (Figure 4A).

In all other respects, Experiment 3 was identical to Experiment 2. Thus, the presence of a bias under these conditions would indicate that the preference is for advancing motion *per se* and is not dependent on the assignment of convex and concave curvatures.

Methods

Subjects

Fifteen Florida Atlantic University undergraduates who did not participate in any of the earlier experiments participated in Experiment 1 or 2 for course credit. All provided written, informed consent as approved by the Florida Atlantic University IRB.

Stimuli and procedure

A schematic diagram of the stimuli is shown in Figure 4B. Each stimulus consisted of two colored regions divided by a sawtooth-shaped border, constructed so that the primary axes of all of the "teeth" were parallel to one another. All other details of the stimuli, as well as the procedure, were identical to Experiments 1 and 2.

Results

We again calculated the percentage of trials on which subject responses were consistent with a figural assignment in which the "moving" region was advancing or receding. The average across all 15 subjects was 76% in favor of advancing ($SE = 0.04$). This preference was highly significant by t-test ($t(14) = 4.65$, $p < 0.0001$). No effect or interaction for relative size or the slope of the contour was observed. Broken down by subject, 13 subjects showed a significant bias for advancing while two showed no bias in either direction.

Experiment 4

The translational motion used in the first three experiments carries two separable effects on the stimulus: 1) the direction of motion of the contour and 2) that the region the contour is bounding is expanding. One possible account for our results is that the expansion of a color region makes it more prominent (e.g., draws attention) and that the bias we observe is due to a saliency difference between the colored regions.[2] In order to test whether an expanding region alone—without the advancing contour motion—is sufficient to produce a bias, Experiment 4 used stimuli in which the *aperture* through which the two colored regions was seen moved at the same rate as the dividing contour in our three earlier experiments (Figure 5). This had the effect of expanding and contracting the two colored regions in precisely the same proportion as if the contour itself had moved, as in Experiments 1–3. If the preference observed in the first three experiments was due to the

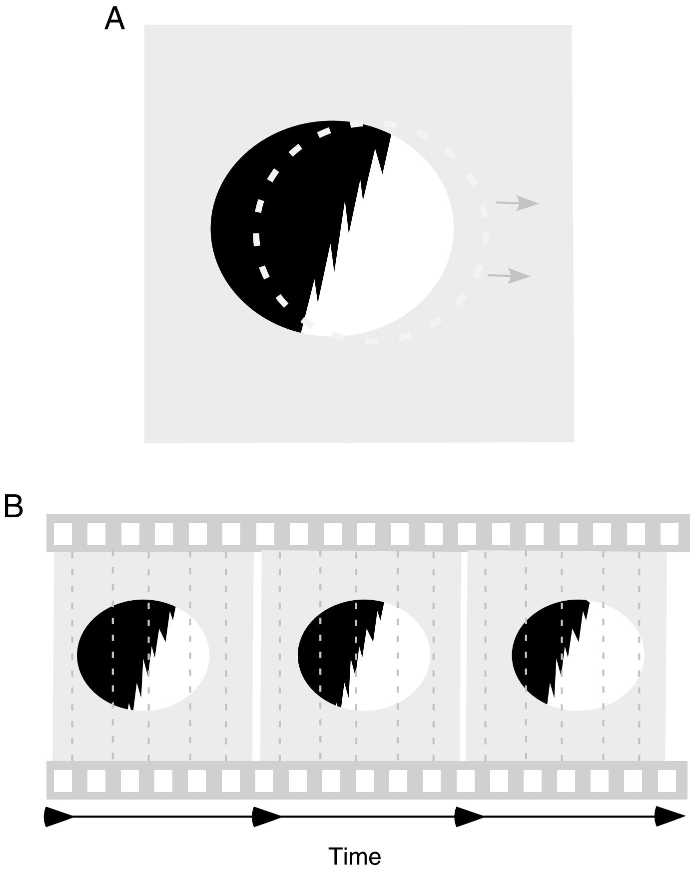

Figure 5. Experimental stimulus from Experiment 4. (A) In this experiment, the *aperture* moved in a direction orthogonal to the pointing direction of the contour teeth rather than the contour. (B) An illustration of a motion sequence. For an animated version, see Movie file "Exp 4.gif" 1 in the Supplementary materials.

change in area of the different regions, then a similar effect would be expected to be present here. If, however, the bias we observed depends on the perceived motion of a contour or the region it bounds, then no similar preference is to be expected when the movement of the aperture itself is the cause of the expansion/contraction of the two colored regions.

Methods

Subjects

Fifteen Florida Atlantic University undergraduates who did not participate in any of the earlier experiments participated for course credit. All provided written, informed consent as approved by the Florida Atlantic University IRB.

Stimuli and procedure

Stimuli were identical to those used in Experiment 3 with the difference that the contour dividing the two colored regions remained static throughout the trial while the aperture through which the contour was viewed moved orthogonally to the pointing direction (i.e., the main axis) of the "teeth" of the contour (Figure 5). The motion of the aperture was equivalent (in terms of speed) to the motion of the contour in Experiment 3 and resulted in the same change in relative area of the two colored regions, albeit without any motion of the dividing contour itself. The procedure was identical to Experiments 1–3 with the exception that subjects were simply instructed to report which color they had seen "in front of the other", as opposed to "moving in front".

Results and discussion

We calculated the percentage of trials on which subject responses were consistent with a figural assignment in which subjects assigned figure to the region that was growing larger by virtue of the aperture motion. The average across all 15 subjects was 55% in favor of the larger region. This preference was not significant by *t*-test ($p > 0.05$). These results suggest that we may reject the hypothesis that subjects in earlier experiments were simply choosing the colored region that grew larger during the motion sequence simply because it was more salient, or for some other reason relating to its relative size. Rather, we claim that the observed bias depends on the translational motion of the dividing contour.

General discussion

Across three experiments, we found a strong and robust preference to assign figure to a contour on the basis of translational motion that is "advancing" rather than "receding" within the field of view. This bias is not due to a preference for approaching in depth (Experiment 2), the "pointing" direction of contour convexities (Experiment 3), nor is it attributable to a simple increase in the size of one region (Experiment 4). Unlike several earlier examples of figure–ground arising from motion such as Kinetic Occlusion (Gibson et al., 1969), Edge-Region Grouping (Palmer & Brooks, 2008) and the Screening Effect (Michotte et al., 1964), our current results cannot be explained by appeal to a simple regularity such as grouping or the accretion or deletion of texture. More specifically, there was no flanking texture in these experiments, and therefore, no grouping cue or texture accretion or deletion was present.

What then might account for the strong perceptual preference observed in these experiments? As mentioned above, assuming a generic viewpoint, a moving object will typically produce advancing and receding motions equally. Thus, the current results might be accounted for by suggesting that moving objects are not typically viewed from a generic viewpoint; perhaps there is a general preference to view the "front", leading edge of moving objects, rather than the "back", trailing edge, in order to track where they are heading. This preference in gaze location would lead to greater exposure to advancing versus receding motion, which might be driving the bias in our ambiguous stimuli.[3]

One ambiguity not addressed in the current study is whether the bias depends on a "surface-based" or "contour-based" preference. In the *surface-based* framework, the preference is to see the motion of a surface whose area is increasing within the field of view, or alternatively, to see the occlusion of a background surface whose area is decreasing. Using the terminology of Kinetic Occlusion studies (e.g., Gibson et al., 1969), this may be described as a preference to see a "deletion" of a background surface that is being progressively occluded by a foreground surface, rather than an "accretion" of a background surface that is being progressively unoccluded by a foreground surface.[4] However, unlike Kinetic Occlusion the accretion/deletion in our study is not inherent in the stimulus (i.e., based on appearing or disappearing texture) but is rather an outcome of the figural assignment itself. An alternative *contour-based* framework for describing our effect is based solely on the motion of the contour itself, without regard to the adjacent regions. According to this latter account, the preference is simply to assign figure to the *opposite* side of the motion of a translating contour—that is to see it as a leading, rather than trailing edge; in this case, the deletion of the background surface is a product of, rather than the reason behind, the figural assignment. Of course, in typical object motion, these two properties—figural polarity of the contour and the accretion or deletion of the surfaces—are always coupled. However, they are not literally identical, since one depends on a property of the internal region while the other only depends on the bounding contour. Nevertheless, there is reason to believe that the visual system expects this constant conjunction between figural polarity and accretion/deletion. In a recent study using holes moving within a surface (generated using binocular disparity) Bertamini and Hulleman (2006) found that subjects would override binocular depth information (i.e., they would not report seeing moving holes but rather a moving lens or "spotlight") so that the figural polarity and accretion/deletion cues were consistent. Future studies will need to be performed in order to tease apart these different possible explanations.

Relation to motion parallax

While not typically though of as a figure–ground cue *per se*, motion parallax—the visual phenomenon whereby closer objects move farther in the visual field than farther ones based on the same absolute motion—is a dynamic cue to *depth* ordering, usually applied to distant objects that do not share a contour. However, it is interesting to note that the kind of translational contour motion shown in our displays can occur not only for moving objects but also for stationary objects separated in depth when the *observer* is in motion. When one object occludes another from an observer's viewpoint, that observer's motion in a translational (i.e., non-depth) direction will result in the visible boundary between the two objects translating in the same manner as when one of the objects moves in such a direction relative to the observer; that is, it will produce advancing or receding motion identical to the translational motion in our present study. Of course, the same symmetry that applies to object motion in our experiments applies to ego-based motion parallax as well; both advancing and receding motions are equally probable as they simply depend on the direction of the observer. However, the presence of a known motion-based cue to depth ordering suggests that the phenomenon described here may be tapping into similar perceptual mechanisms.

Dynamic cues to figure–ground assignment

The vast majority of studies on figure–ground assignment has only considered static stimuli. As this study, along with those of Barenholtz and Feldman (2006) demonstrate, the motion of contours, even in the absence of neighboring texture, can serve to disambiguate stimuli in the absence of—or even in opposition to—standard static cues to figure–ground. One particularly interesting aspect of such contour-based motion cues is that they can be defined based on a small *local* region of the contour. Many static cues to figure–ground assignment on the other hand (e.g., closure, smaller area, symmetry, and familiarity) depend on computing more *global* properties of an extended contour, or, in the case of texture-based cues (e.g., Palmer & Brooks, 2008), from neighboring regions. Indeed, the local nature of the kinds of motion-based cues described here was highlighted in a recent study by Kim and Feldman (2008), in which they found that a dynamic cue can lead to globally *inconsistent* figure–ground assignment (i.e., cases in which one local section of a contour was assigned opposite figural polarity to another section of the same contour). Since local computations demand different (and typically less) computational resources than global ones, dynamic cues may be expected to play a significant role in visual processing where applicable. This observation may account for why dynamic cues sometimes supersede static cues in these experiments.

While motion and form processing are often assumed to be distinct and perhaps subserved by independent neural pathways, our current results add to an already significant literature documenting instances where motion leads directly to form perception. Earlier examples of psychophysical results include Kinetic Occlusion (Gibson et al., 1969;

Kaplan, 1969), motion-based grouping (i.e., common fate), structure-from-motion (Ullman, 1979; Wallach & O'Conell, 1953), and the integration of coherent motion across space (Adelson & Movshon, 1982; McDermott, Weiss, & Adelson, 2001). Recent evidence from neurophysiology also points to a blurring between motion and form processing in the brain (Braddick, O'Brien, Wattam-Bell, Atkinson, & Turner, 2000; Lorenceau & Alais, 2001). The "advancing bias" described here further highlights the potentially complex interaction between motion and form processing: The motion of the contour in these studies ultimately determines the "form", since the polarity of figural assignment at contour points determines the sign of curvature, which in turn influences the phenomena shape of the surface bounded by the contour.

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Footnotes

[1] The colors of the two different regions were each chosen by randomly selecting two points in RGB color space (with values chosen from between 200 and 255 for each component of the triple) that were at least 50 points in Euclidian distance from one another in the color space.

[2] Note that in its simplest form, this explanation conflicts with the standard observation that smaller areas are typically associated with figure.

[3] This theory was suggested to the first author by Stephen Palmer, of the University of California at Berkeley, during a meeting of *Vision Sciences Society*.

[4] We thank an anonymous reviewer for suggesting this possible relationship to the accretion/deletion effects in other studies.

References

Adelson, E. H., & Movshon, A. (1982). Phenomenal coherence of moving visual patterns. *Nature, 300,* 523–525. [PubMed]

Bahnsen, P. (1928). Eine untersuchung uber symmetrie und asymmetrie bei visuellen wahrnehmungen. *Zeitschriftfur Psychologie, 108,* 129–154.

Barenholtz, E., & Feldman, J. (2006). Determination of visual figure and ground in dynamically deforming shapes. *Cognition, 101,* 530–544. [PubMed]

Barenholtz, E., & Tarr, M. J. (2008). Visual judgment of similarity across shape transformations: Evidence for a compositional model of articulated objects. *Acta Psychologica, 128*, 331–338. [PubMed]

Bertamini, M., & Hulleman, J. (2006). Amodal completion and visual holes (static and moving). *Acta Psychologica, 123,* 55–72. [PubMed]

Braddick, O. J., O'Brien, J. M. D., Wattam-Bell, J., Atkinson, J., & Turner, R. (2000). Form and motion coherence activate independent, but not dorsal/ventral segregated, networks in the human brain. *Current Biology, 10,* 731–734. [PubMed] [Article]

Gibson, J. J., Kaplan, G. A., Reynolds, H. N., & Wheeler, K. (1969). The change from visible to invisible: A study of optical transitions. *Perception & Psychophysics, 5,* 113–116.

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.

Kaplan, G. A. (1969). Kinetic disruption of optical texture: The perception of depth at an edge. *Perception and Psychophysics, 6*, 193–198.

Kim, S.-H., & Feldman, J. (2008). Globally inconsistent figure/ground relations induced by negative parts [Abstract]. *Journal of Vision, 8*(6):721, 721a, http://journalofvision.org/8/6/721/, doi:10.1167/8.6.721.

Koffka, K. (1935). *Principles of Gestalt psychology*. New York: Harcourt.

Lorenceau, J., & Alais, D. (2001). Form constraints in motion binding. *Nature Neuroscience, 4,* 745–751. [PubMed]

McDermott, J., Weiss, Y., & Adelson, E. H. (2001). Beyond junctions: Nonlocal form constraints on motion interpretation. *Perception, 30,* 905–923. [PubMed]

Michotte, A., Thines, G., & Crabbe, G. (1964). *Les complements amodaux des structures perceptives (Studia psychologia)*. Louvain, Belgium: Publications Universitaires de Louvain.

Nakayama, K., & Silverman, G. H. (1988). The aperture problem—I. Perception of nonrigidity and motion direction in translating sinusoidal lines. *Vision Research, 28,* 739–746. [PubMed]

Palmer, S. E., & Brooks, J. L. (2008). Edge-region grouping in figure-ground organization and depth perception. *Journal of Experimental Psychology: Human Perception and Performance, 34,* 1353–1371. [PubMed]

Palmer, S. E., Brooks, J. L., & Nelson, R. (2003). When does grouping happen? *Acta Psychologica, 114,* 311–330. [PubMed]

Peterson, M. A., & Gibson, B. S. (1993). Shape recognition contributions to figure–ground organization in three-dimensional displays. *Cognitive Psychology, 25,* 383–429.

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

Rubin, E. (1921). Visuaell wahrgenommene figuren [figure and ground]. Copenhagen: Gyldendalske. (Excerpt reprinted in Yantis, S. (Ed.), *Visual Perception*, Taylor & Francis, Philadelphia, 2001).

Stevens, K. A., & Brookes, A. (1988). The concave cusp as a determiner of figure-ground. *Perception, 17,* 35–42. [PubMed]

Ullman, S. (1979). *The interpretation of visual motion*. Cambridge, MA: MIT Press.

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. [PubMed]

Wallach, H., & O'Connell, D. N. (1953). The kinetic depth effect. *Journal of Experimental Psychology, 45,* 205–217. [PubMed]

Yonas, A., Craton, L. G., & Thompson, W. B. (1987). Relative motion: Kinetic information for the order of depth at an edge. *Perception & Psychophysics, 41,* 53–59. [PubMed]