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Determination of visual figure and ground in dynamically deforming shapes ☆

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Abstract

Figure/ground assignment – determining which part of the visual image is foreground and which background – is a critical step in early visual analysis, upon which much later processing depends. Previous research on the assignment of figure and ground to opposing sides of a contour has almost exclusively involved static geometric factors – such as convexity, symmetry, and size – in non-moving images. Here, we introduce a new class of cue to figural assignment based on the motion of dynamically deforming contours. Subjects viewing an animated, deforming shape tended to assign figure and ground so that articulating curvature extrema – i.e., ''hinging'' vertices – had negative (concave) contour curvature. This *articulating-concavity bias* is present when all known static cues to figure/ground are absent or neutral in each of the individual frames of the animation, and even seems to override a number of well-known static cues when they are in opposition to the motion cue. We propose that the phenomenon reflects the visual system's inbuilt expectations about the way shapes will deform – specifically, that deformations tend to involve rigid parts articulating at concavities.

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1. Introduction

Figure/ground assignment is a critical step in early visual computations, determining the depth ordering of surfaces, with figural regions interpreted as occluding a more distant ground (Rubin, 1921). Figure/ground assignment is also essential in determining apparent visual shape, as the polarity of figural assignment at contour points determines the sign of curvature, which in turn influences phenomenal shape (Attneave, 1971; Hoffman & Richards, 1984). (Convex and concave contour regions are considered to have positive and negative contour curvature, respectively.) Figure/ground assignment is generally thought to be preattentive (Driver, Baylis, & Rafal, 1992, though see Vecera, Flevaris, & Filapek, 2004). Neural correlates of the figure/ground distinction appear as early as primary visual cortex, where cellular responses vary depending on whether the location is "owned" by figural or ground regions (Lamme, 1995; Zhou, Friedman, & von der Heydt, 2000) and also in inferior temporal cortex, where response to shapes differs depending on whether the shape is perceived as figure or ground (Baylis & Driver, 2001).

Previous research has identified a number of cues that influence the assignment of figure and ground to opposite sides of abounding contour, including size (Koffka, 1935; Rubin, 1921) (smaller areas assigned to figure), 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). Generally these studies have only investigated stationary images containing static contours. One recent exception is a phenomenon described in Palmer, Brooks, and Nelson (2003), in which a translating contour is seen as bounding the region in which a group of dots are moving in "common fate" with the contour, presumably reflecting grouping mechanisms. Somewhat surprisingly, however, research on figure and ground has generally not included a potentially rich source of information: the dynamic properties of the motion of the contour itself. The shape of many objects – particularly biological ones – frequently changes due to natural movement, such as the articulation of body parts and limbs. Such motion carries information that is not present in any static view of the image. While a considerable body of research has documented the relations between form and motion processing both in terms of psychophysics (Adelson & Movshon, 1982; McDermott & Adelson, 2004; Shiffrar, Li, & Lorenceau, 1995; Sinha, 2001) and neurophysiology (Braddick, O'Brien, Wattam-Bell, Atkinson, & Turner, 2000; Lorenceau & Alais, 2001; Murray, Olshausen, & Woods, 2003) these studies have typically only involved rigid motions, such as translations in the plane or rotations in 3D, and have not considered motion produced by shape deformations.

How might dynamic shape deformation influence figural interpretation? It is well known that contour points with maximally negative curvature (concavities of locally extreme curvature, called *negative minima)* tend to be perceived as boundaries between parts of the shape (Hoffman & Richards, 1984; Hoffman & Singh, 1997) a subjective judgment that has objective psychophysical correlates (Barenholtz & Feldman, 2003). We speculated that the visual system might expect shapes to deform via articulation of rigid parts hinged at vertices with negative curvature. As mentioned, the sign of curvature of a contour is determined by figure/ground assignment, with concave (negatively curved) regions and convex (positively curved) regions by definition switching places when figure/ground is reversed. Hence for a bending contour to be perceived as a part articulating at a concavity – i.e., a part boundary – it suffices for the visual system to assign figural status so that contour points serving as ''hinges'' between rotating edges have negative curvature.

For example, Fig. 1A shows a contour whose figure/ground assignment is perfectly ambiguous when viewed statically; the figure can be perceived a either a black ''comb'' over a white background, or a white comb over a black background. The two complementary shapes are precisely equated in terms of all known figure/ground cues, such as area, convexity, symmetry, and familiarity. Indeed the black and white regions have the same shape, and hence all form cues to figure/ground are necessarily equated. However when the figure is set in motion by shifting the rightward-pointing vertices up and down (see panels B and C; examples of motion stimuli can be viewed at http://cog.brown.edu/~elan/Articulation_Demos.html), the two possible assignments now lead to very different dynamic percepts: one (black as figure) in which convex triangular ''teeth'' are articulating at concave fulcra and another (white as figure) in which the concavities are themselves in motion, hinged at convex fulcra. However, these two possible interpretations do not seem equally strong perceptually; subjects ($N = 7$) shown these displays reported a figural assignment in which the concavities served as stationary fulcra (black in this example) 75.99% of the time (se = 1.94%). This preference was highly significant by *t*-test for deviation from chance response ($t(6) = 39.1, p < .0001$).

In addition to being inattributable to known figure/ground cues (because none are present in any of the individual frames), this preference cannot be explained by known principles of motion organization, such as the Gestalt law of ''common fate'' (Wertheimer, 1923) which holds that visual elements undergoing similar motion tend to be grouped together. While the opposite sides of each perceived part in the displays do indeed move together, exactly the same is true of the sides of distinct parts (i.e., the opposite sides of ground regions). Hence common fate does not favor either figure/ground assignment. Instead, the preference points to an underlying expectation about dynamic shape deformation – that shapes articulate at concave joints between relatively rigid parts.

2. Experiment 1

The simple example illustrated in Fig. 1 involves a number of dynamic features that are endemic to typical articulating parts, with multiple edges moving in unison,

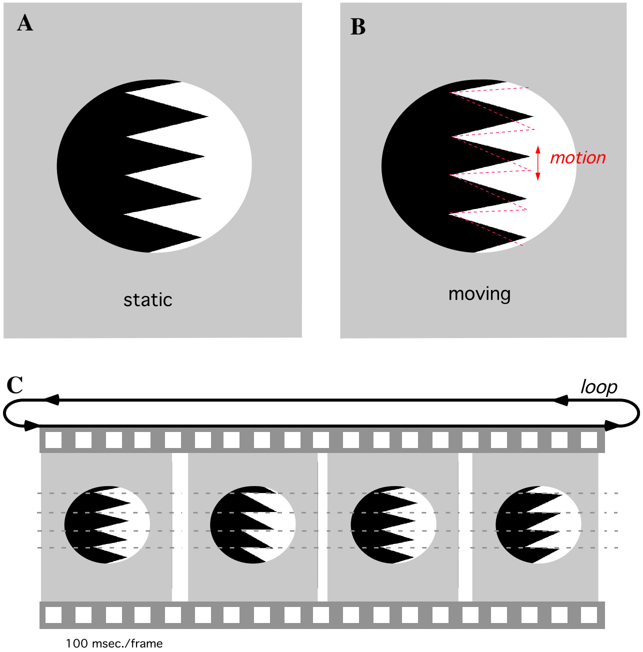

Fig. 1. A static stimulus with ambiguous figure/ground can give rise to a clear figural assignment when placed in motion. (A) Static case. A polygonal contour divides black and white regions behind a virtual "window." Figure/ground is ambiguous: it can be seen as either a black comb-like figure on a white background, or vice-versa. Notice that when figural assignment changes, concavities and convexities along the dividing contour switch places. (B) Motion case (schematic). (C) Motion case (one complete animation cycle is shown). All of the vertices on one side of the comb (here right) are shifted up and down in a repeated 4-frame cycle. Note that each individual static frame maintains the figure/ground ambiguity, and the contour motion is equally shared by the black and white regions (because the moving points form the *boundary* between the black and white regions). Nevertheless most people report a strong preference for a figural assignment in which the moving vertices are convex and the stationary vertices are concave. That is, the black "teeth" appear to wave up and down in front of a more distant white background, consistent with rigid articulating parts, hinged at concave "joints."

and some extrema in motion with others static, leaving it unclear which cues were critical in determining the effect (for example, perhaps there is a preference to see moving extrema as convex). In our formal experiments we sought to isolate the critical factor or factors more precisely. Specifically, we speculated that the effect might rest – at least in part – on a simple rule: assign figural status so that the articulating vertex is concave. To test for such an *articulating-concavity bias*, we created displays containing only a *single* articulating vertex among a group of stripes, and no common contour motion at all (see Fig. 2A). We simply asked subjects *which color* appeared to be moving, as the border, and thus its motion, is perceptually "owned" by the figure rather than the ground (Baylis & Driver, 1995; Nakayama, Shimojo, & Silverman, 1989; Rubin, 1921). (Objectively, of course, what is really moving is the border *between* the two colors, but our subjects seemed to find the question natural,

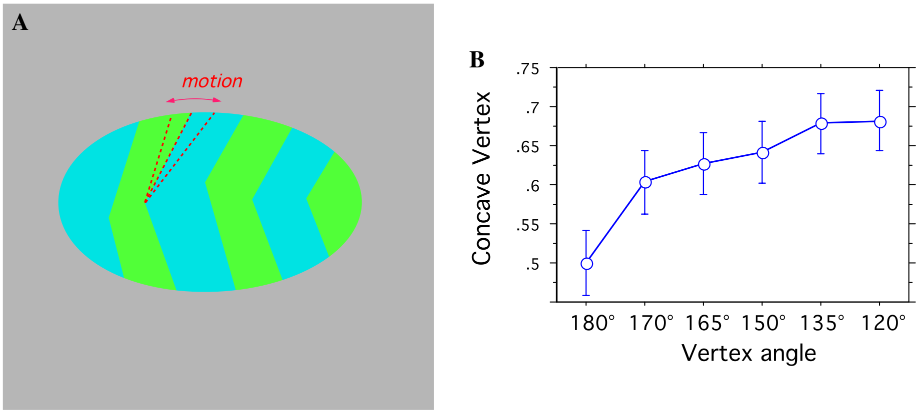

Fig. 2. (A) Stimulus from Experiment 1. When static, figure/ground is neutral, and the image can be seen as green stripes on a blue background or vice-versa. (The borders between stripes are slightly randomized in order to avoid a regular or "textured" appearance, but the areas of the alternating stripes are equal on average.) When a single edge is set in motion, hinged at the critical vertex as illustrated, most observers assign figure so that the articulating vertex is concave (in the illustration, green as figure and blue as background). (B) Proportion articulating-concavity responses as a function of the sharpness of the vertex angle. As the angle grows sharper, the tendency to interpret it as a part boundary grows stronger, and consequently the bias to assign it negative curvature, forcing green in front. Error bars in all plots represent $\pm$ one standard error.

and debriefing confirmed that their responses corresponded to which color they saw as in front.) An articulating-concavity bias would lead to subjects' favoring the figural assignment that assigns negative curvature to the articulating vertex. It is important to stress that, unlike the display described in Fig. 1, the choice of figural assignment here does not determine whether the motion involves *parts* or not, since according to either interpretation it is a single contour of an apparent part that is moving. However, we theorized that since typical part motion involves articulations at concavities, the visual system may maintain a preference with regard to the isolated contour. We also manipulated the sharpness of the angle at the vertex, because greater magnitude of curvature at concavities is associated with more salient part boundaries (Barenholtz & Feldman, 2003; de Winter & Wagemans, in press; Hoffman & Singh, 1997), so we reasoned that any preference for articulating concavities would increase with the sharpness of the angle at the vertex.

2.1. Methods

2.1.1. Subjects

Seven Rutgers students naive to the purpose of the experiment participated for cash payment.

2.1.2. Stimuli and procedure

Stimuli were computer-generated animation sequences consisting of 12 consecutively presented frames of 100 ms, duration each for a total of 1.2 s for the entire animation sequence. Each animation frame consisted of a central ovoid annulus measuring approximately 8° of visual H × 11° of visual angle W, on a gray background and divided into blue and green regions by a series of horizontally aligned v-shaped contours. The central vertex of each v-shaped contour had a horizontal position approximately 2° of visual angle horizontally from its neighbor, and varied randomly between 0° and 3° of visual angle, either up or down, from the vertical center of the screen. No v-shaped contour ever overlapped with its neighbor. On each trial, the horizontal phase of the pattern within the annulus was randomly assigned and the entire stimulus (pattern and annulus) was randomly rotated between 0° and 30° in the clockwise or counterclockwise direction. Motion was produced by rotating one of the top edges of one of the v-shaped contours 10 angular degrees (note: not visual angle), clockwise and counterclockwise, in a 4-frame cycle (see Fig. 2). (Note that, unlike the previously described demonstration (Fig. 1) only a single edge was moved here since moving all of the edges in these displays would have rendered the notion of assigning f/g on the basis of sign of curvature of the articulating vertex meaningless, since any figural assignment would contain both articulating concavities and convexities.) The number of cases in which the predicted figural assignment (i.e., in which the articulating vertex is concave) was blue and green were included. There were six levels of the (initial) vertex angle, ranging from 180° (straight) and 120°.

2.2. Results and discussion

Fig. 2B shows the proportion of trials on which subjects assigned figure so that the articulating vertex had negative (concave) curvature. At 180°, the vertex is "straight" and there is no visible part boundary at all, so subjects are at chance (50% response for each figure/ground assignment). (More precisely, at 180° there is no vertex visible at all when the display is static, while once set in motion the vertex alternates between bending one way and bending the other way, leaving it neutral between concavity and convexity regardless of figural assignment.) But as the angle becomes more acute (and now consistently bends one way) it makes a sharper and more convincing part boundary; so the bias to interpret it as concave grows stronger, inducing the observed figural assignment (in Fig. 2, green in front). Overall, with the 180° condition removed, there was a preference for concave fulcra (mean = 63%, se = 3%). A t-test for deviation from chance found that this preference was significant, $t(6) = 3.936$, $p = .0056$. A linear regression showed a significant relationship between the sharpness of the angle and the probability of a concave response ($\beta = -.003$, $p = .0053$). (Note that here and elsewhere the measured preference is substantially below 100%, due to the polluting contributions of hysteresis and individual subjects' color preferences, which add variance and suppress the absolute magnitude of the effect; however, as trial order was randomized and colors were counterbalanced, these factors do not impact the qualitative interpretation of the results.)

3. Experiment 2

Experiment 1 establishes that the dynamic cue of an articulation can serve to disambiguate figure and ground in an image. We next sought to assess the relative strength of this novel motion-based cue by putting it in competition with some well-known static figure/ground cues. One simple variation of the previous experiment is to make the sizes of the alternating stripes unequal (Fig. 3), in which case there is a known bias to perceive the narrower stripes as figure and the wider as ground (Rubin, 1921). What will happen when the relative area of the stripes and the motion of an articulating edge lead to opposite predictions with regard to figural assignment? In order to establish a basis of comparison, we first had each subject perform a conventional figure/ground assignment task using static stimuli and then perform a separate block of trials in which a single edge was set in motion as in the previous experiment.

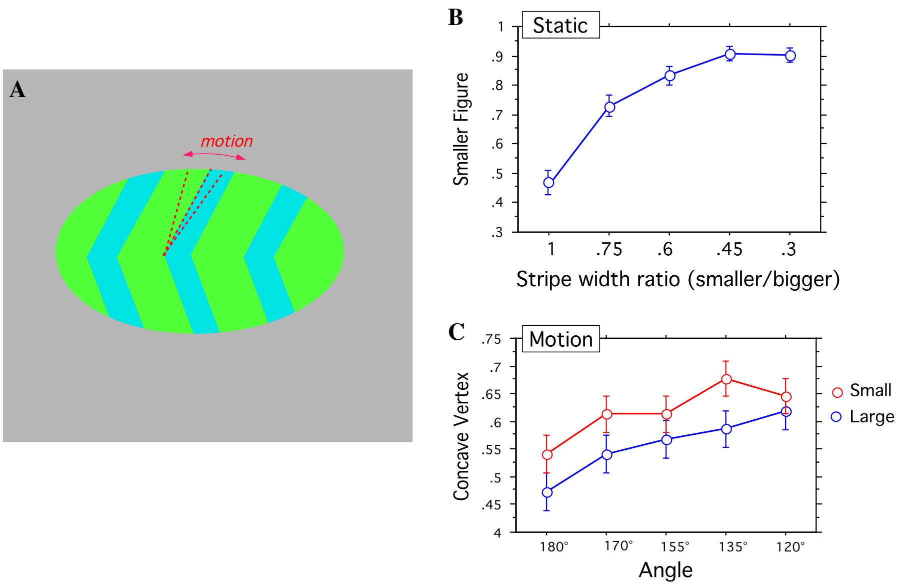

Fig. 3. (A) Stimulus from Experiment 2; display with unequal-area stripes. (B) Data from the static condition, showing the proportion of narrow-in-front responses as a function of the stripe width ratio. The bias to assign the smaller areas to figure increases as the size ratio grows more extreme. (C) Data from the motion condition, showing the proportion of trials on which subjects assigned figure such that the articulating vertex was concave. The data is divided into "small" and "large," referring to the size of stripe that would be in front (figure) if the critical vertex were interpreted as concave. The consistently higher responses for small over large trials means that subjects generally preferred to see narrow stripes as figural; this tendency was stronger when it was consistent with the articulating-concavity, but was overridden when it conflicted with it, especially at sharper angles. Thus subjects generally saw articulating-concavity interpretations even when they forced the wide stripes to be figural.

3.1. Methods

3.1.1. Subjects

Six new naive subjects participated in the experiment for cash payment.

3.1.2. Stimuli and procedure

Stimuli and motion were generated as in the previous experiment, with the exception that the width of the stripes varied between 0.7 (narrowest) and 2.3 (widest) degrees of visual angle and the central vertices were aligned vertically in order to control the area of the stripes. Each subject performed two blocks of trials: a static block and a motion block. In the static block the stimulus consisted of the same animation frame shown for the entire 1.2 s interval. In the motion block, an animation was displayed as described in Experiment 1. On exactly half of the trials this articulation cue was in opposition to the smaller-area cue while on half it was consistent with the area cue.

3.2. Results and discussion

Fig. 3B confirms that in the static case our subjects strongly favor the narrow-in-front interpretation, a preference that increased with the difference in area, an expected result. However, Fig. 3C shows that in motion displays, while some preference for narrower stripes persisted, this preference was mitigated and even reversed (at sharper angles) once motion was introduced. Collapsing across all size conditions, there was a significant preference for seeing the articulating vertex as concave (mean = 60%, se = 1%, $t(5) = 3.116$, $p = .0207$). Only including those trials in which assigning concave sign to the articulating vertex led to the larger stripes being seen as figural, this preference was only significant at the two sharpest angles ($t(5) = 2.895$, $p = .0340$). However, it is important to note that even at the less sharp angles, the preference for smaller as figure is no longer present, i.e., the preference for concavity appears to "balance" the preference for smaller area. Thus, these results suggest that the dynamic articulating cue can mitigate and actually supersede the static cue of area when the two are in conflict.

4. Experiment 3

We next pitted the articulating-concavity bias against another well-known static figure/ground cue, convexity. There is a well-established bias to see convex regions as figural (Kanizsa & Gerbino, 1976). For example, in Fig. 4, the displays can be interpreted as a series of convex diamonds (in the figure, green) in front of a background (in the figure, blue); or, alternatively, as a series of concave "bowties." As in Experiment 2, here the static version is not neutral, but exhibits a marked convexity bias (diamonds in front). With motion of the edges however (as schematized in the figure) the dynamic articulation cue favors the bow-tie interpretation (while not affecting the convexity cue). As in the previous experiment, we varied the angle at

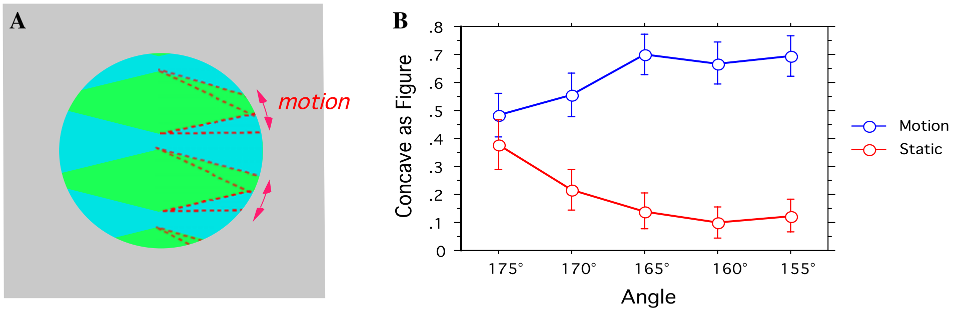

Fig. 4. (A) Display in which articulating-concavity bias competes with a static convexity cue. In the motion condition all of the edges on one side of the diamond/bowtie figures move up and down in a 4-frame cycle. Each subject performed a static block, followed by a motion block. (B) Data in the static condition (lower curve), the convex regions are seen more often as figure, increasingly so as angle at the critical vertices is made more acute. But in moving displays (upper curve), the opposite interpretation dominates, increasingly so as the angles get sharper.

the critical vertex. This angle modulates both competing factors, convexity (in both static and motion displays) and the articulating-concavity bias (in motion displays) – but in opposite directions: as the angle becomes sharper, the convexity cue more strongly favors the convex-as-figure interpretation (diamonds in front). However, as noted, sharper curvature at concavities are also associated with more salient part boundaries (Hoffman & Singh, 1997), so the articulating motion cue favoring the concave-as-figure interpretation also increases with sharper angle.

4.1. Methods

4.1.1. Subjects

Six Rutgers students naive to the purpose of the experiment participated for cash payment.

4.1.2. Stimuli and procedure

Stimuli were computer-generated animation sequences consisting of 12 consecutively presented frames of 100 ms, duration each for a total of 1.2 s for the entire animation sequence. Each animation frame consisted of a central circular annulus, measuring approximately 8° visual angle in diameter, on a gray background and divided into blue and green regions by a series of alternating upright and inverted v-shaped contours. Each diamond/bowtie shape measured between 1° and 1.5° in height (at their tallest point), depending on the angle at the vertex. Motion was generated by shifting the (occluded) endpoints of the v-shaped contours from which the figure was constructed approximately 0.5° up and down in a repeated 4-frame cycle. The entire display was randomly rotated between 30 angular degrees clockwise or counterclockwise on each trial. An equal number of cases in which the predicted figural assignment (i.e., in which the articulating vertex is concave) was blue and green were included. There were six levels of vertex angle included between 180° (straight) and 120°. There were 5 levels of angle of the vertex, ranging between 175 and 155 angular degrees. In order to confirm the presence of a convexity cue in these displays, each subject performed a block of trials in which the display was static (the same image for 1.2 s) and one in which there was motion as described above. Unlike earlier experiments, the concavity/convexity asymmetry was present in both the static and dynamic stimuli. The static block was always presented first, as we sought to assess subjects' naive responses to the static stimuli without regard to any potential motion, which we suspected might bias them towards a concave response.

4.2. Results and discussion

Fig. 4B shows the proportion of trials on which subjects chose a figural assignment consistent with concave articulating vertices (i.e., the bow-tie interpretation) as a function of angle at the vertex, split by whether it was the motion or static block. The divergence between the static and motion interpretations (lower and upper curves, respectively) can clearly be seen. In the static displays, subjects preferred the convex diamond interpretation, and thus were unlikely to choose the bow-tie interpretation (mean = 23%, se = 1%; $t(5) = 4.757$, $p = .0051$). However, in the motion block this preference reversed and subjects were more likely to choose a concave interpretation (mean = 61%, se = 2%, $t(5) = 25.783$, $p < .0001$). Both preferences increased as the angle at the vertex grew sharper ($\beta = -.01$, $p < .0001$ by regression for both conditions). Thus although there was a strong convexity bias when displays were static, this preference was clearly overridden when motion was introduced.

5. Experiment 4

Finally, to investigate the limits of the phenomenon, we constructed a highly simplified class of stimuli consisting of a single central vertex in a circular annulus (Fig. 5). Depending on figural assignment, these displays can be seen either as a "Pac-man" with a hinged jaw, or, alternatively, as a wedge of pie in an otherwise empty plate (Fig. 5A). The static version of these stimuli favors the wedge interpretation based on *two* distinct cues: smaller area (the wedge is smaller than the pac-man) and convexity (the wedge is convex and the pac-man is not). But when the central vertex is set articulating, the articulating-concavity bias would tend to induce the converse interpretation, in which the articulating "mouth" of the pac-man is figure.

5.1. Methods

5.1.1. Subjects

Five new naive subjects participated in the experiment for cash payment.

5.1.2. Stimuli and procedure

As in the previous experiment, each subject performed a static block as well as a motion block. Displays measured approximately 8° of visual angle in radius. Motion

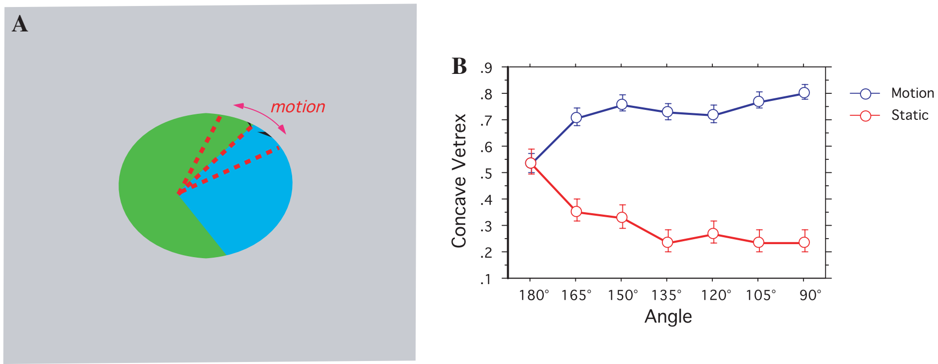

Fig. 5. (A) Stimulus from Experiment 3; display with a single articulating vertex, perceived either as a small, convex pie-wedge on a plate, or a "Pac-man" with a hinged jaw. (B) Data, showing the smaller-area and convexity biases operative in static displays (lower curve), but overridden by the articulating-concavity cue in motion displays (upper curve).

consisted of a single edge, anchored at the central vertex, rotating 15 angular degrees clockwise and counterclockwise in a repeated 4-frame cycle. The entire display was randomly rotated between 0° and 30° clockwise or counterclockwise (determined randomly) on each trial. The task was identical to that in Experiments 1 and 2.

5.1.3. Results and discussion

Fig. 5B shows the proportion of trials on which subjects chose a figural assignment consistent with concave articulating vertices (i.e., the pac-man interpretation) as a function of angle at the vertex, split by whether it was the motion or static block. The data shows clearly that the articulating-concavity bias again predominates. In the static condition, subjects tended to prefer the pie-wedge interpretation and thus were unlikely to report the pac-man (mean = 28%, se = 1%, $t(4) = 12.99$, $p < .0001$), as predicted by the conventional cues; but the pac-man as figure in the motion displays (mean = 75%, se = 1%, $t(4) = 19.57$, $p < .0001$), as predicted by the articulating-concavity bias. As before, the data are plotted as a function of the angle at the central vertex, which modulates the convexity and area cues, as well as – in the opposite direction – the dynamic articulation cue. As this angle is made sharper, the dynamic and static interpretations increasingly diverge; in the motion case, the articulating-concavity cue increasingly dominates over the traditional cues.

6. General discussion

We conclude that the visual system has a strong bias towards interpreting articulating vertices as concave. The tendency cannot be accounted for by known principles of motion interpretation, nor by any known static cues to figure/ground assignment, and indeed seems to take precedence over the well-known area and convexity cues. The articulating-concavity bias has a natural interpretation in terms of the visual system's expectations about how naturally occurring shapes changes are liable to deform. Many theories of shape and motion assume models that are internally rigid (Hoffman & Bennett, 1985, 1986; Longuet-Higgins & Prazdny, 1980; Ullman, 1979) but it is clear that the visual system must also recognize and interact with objects whose shape deforms – for example, in the common pattern of articulation at hinged joints. Indeed, studies of point-light figures (Johansson, 1973) have demonstrated that the visual system is remarkably sensitive to the motion patterns of rigid bodies connected at axial joints, and interpretation of biological motion displays is even known to respect biological constraints on physiologically plausible body motions (Chatterjee, Freyd, & Shiffrar, 1996). These studies have generally involved points sampled from the interior of the shape (usually at the joints themselves), rather than along the outer contour. But, as illustrated in our displays, articulation of limbs also produces signature deformations of the bounding contour. From a computational point of view, point-light displays are more readily interpreted under the assumption of internally rigid parts, i.e., that non-rigid deformations occur only at joints (Hoffman & Flinchbaugh, 1982). This leads to motion in which articulations tend to occur at concavities (i.e., putative part-boundaries) while the motion itself will typically involve mostly convex, rigid parts (see Fig. 6). Our findings suggest that the visual system maintains a bias with regard to figural assignment that is consistent with this regularity of natural motion.

It should be noted that, although the current results demonstrate a strong assumption by the visual system that articulating vertices are concave, the possible functional role of such a bias in performing figure/ground segregation is less clear. Since multiple cues to figure and ground are often present when parts articulate (as noted above), the articulating vertex might only play a small role in typical segregation. On the other hand, the highly localized nature of this cue (unlike other cues which tend to depend on global contour properties) might give it some additional utility. Indeed, in our study, the dynamic cue tended to override other, more global cues. In general, the interaction between local and

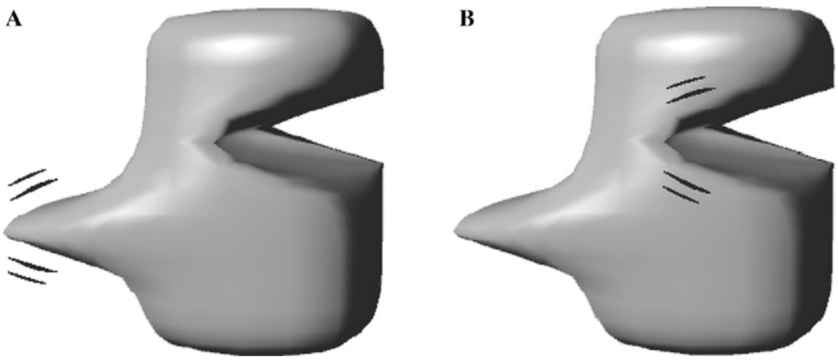

Fig. 6. (A) Typical articulatory deformation, with hinging concavities. (B) Atypical deformation, with hinging convexities.

global cues in figure/ground assignment remains poorly understood, and hence the exact role of the articulating-concavity bias under natural conditions awaits future research.

Regardless of its ultimate role in figure/ground segmentation, the new phenomenon adds to a growing literature highlighting the importance of concavities in the representation of shape. In previous work, we have found that shape changes near concavities along the bounding contour are, all else being equal, more detectable than those near convexities (Barenholtz, Cohen, Feldman, & Singh, 2003; Cohen, Barenholtz, Feldman, & Singh, 2005). This naturally raises the question of whether there might be a connection between the deformations in the current experiments, in which figure and ground are assigned so that articulating points are concave, and these previous results, in which points unambiguously assigned as concave are more likely to be seen changing. The two phenomena cannot be linked too directly, as the earlier results presupposed a firmly assigned figure/ground polarity and thus sign of curvature (stimuli were figurally unambiguous closed shapes), whereas in the current displays the determination of figure and ground was ambiguous by design, being the subject's task to determine. Thus in our current displays one cannot say objectively which type (concave or convex) of extremum was, in fact, "changing," except in the mind of the subject once he or she assigns figure and ground. However, we believe the current results do shed light on *why* the visual system assigns an enhanced status to concavities, as shown in our previous studies. The assumption that articulating vertices are concave is presumably mirrored by an expectation that unambiguously concave extrema may articulate. That is, concave regions may provide a means of *predicting* how an object may deform, based on its geometry, even when no motion is observed – a possibility with strong implications for the recognition of, and interaction with, articulating objects. Thus both phenomena highlight the importance of concavity and convexity, as well as the subtle interplay between figure and ground, and inside and outside, in the visual representation of shape (Subirana-Vilanova & Richards, 1996). The articulating-concavity bias, in particular, points to a prominent, and largely overlooked, role of dynamic factors in the representation of shape and objects.

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