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A new visual illusion of relative motion☆

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Abstract

We present a remarkably simple illusion that manifests whenever a certain class of flat static patterns are moved across our peripheral visual field. A relative motion is perceived in a direction perpendicular to the true motion. Translatory, looming, and rotational movements of the head or the pattern can all elicit it. Each pattern is constructed of simple elements that define, through luminance, an orientation polarity. This polarity could be encoded by spatiotemporally tuned, orientation sensitive units in area V1. We offer an explanation for the illusion based on how such units from V1 may be combined to feed the processes that subsequently interpret motion.

Keywords: Relative motion; Flat static patterns; Peripheral visual field

1. Introduction

New aspects of visual motion perception may be elucidated by the remarkably simple illusion presented here. It manifests itself when a certain class of flat static patterns are moved across our visual field: a relative motion is perceived in a direction perpendicular to the true motion. It is not an explicit aperture effect because no apertures are involved. Translatory, looming, and rotational movements of the head or the pattern can all elicit it. Thus it is unlikely to be due to particular head or eye movement mechanisms (Carpenter, 1988). Each pattern is constructed of simple elements that define, through luminance, an orientation polarity. The properties of this polarity might be coded by spatio-temporally tuned, orientation sensitive cells found in area V1 of primary visual cortex. In the following sections we first demonstrate the illusion before offering an explanation based on how V1 units may be combined to feed subsequent motion interpretation processes.

2. Demonstration of the illusion

The new illusion is illustrated in Figs. 1–3. In particular, the inner and outer rings of the concentric circles in Fig. 1 appear to rotate against each other as the eye is moved continuously closer to the paper (looming) while the gaze is kept fixed on the central spot. Moving out again reverses the direction of the illusory rotation. As does systematically reversing the polarity (not just luminance contrast) of the square elements that comprise the rings — see Fig. 2. Note that each ring only contains elements of a single polarity (defined below): the inner and outer rings being of opposite polarity. Moreover: (1) turning the same rings about their common center makes the gap between them appear to expand or contract; (2) mapping the square elements into vertical columns — see Fig. 3 — and subjecting them to horizontal translation produces a vertical inter-column shearing motion; and conversely (3) vertical translation of the same columns produces an inter-column expansion or contraction.

☆ Baingo Pinna discovered the illusion; both authors contributed equally.

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3. A limiting case

An informative limiting case is that shown in Fig. 4 where there is only a single pair of square elements. To obtain an illusion when looming one needs to fixate not on the elements but away from them — e.g. on the dark spot. (Observing with the left eye closed avoids interaction with the blind-spot.) Thus the illusion seems to distort peripheral rather than foveal vision. Remarkably even the single pair can produce a strong perpendicular impulse velocity. Although this impulse is brief it is of roughly equivalent speed as when there was complete ring — Fig. 1. This observation suggests that the brain mechanisms that produce our perception of coherent motion (Ramachandran & Anstis, 1983; Williams, Phillips & Sekuler, 1986) probably only propagate the illusion, and might not actually generate it.

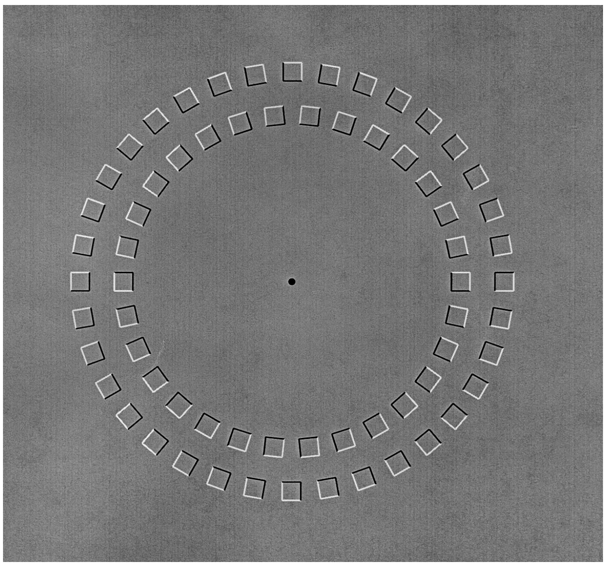

Fig. 1. A new visual illusion of relative motion: Concentric rings comprised of elements of opposing polarity appear to rotate against each other upon looming the central spot. Upon rotation the gap between the circles appear to expand or contract.

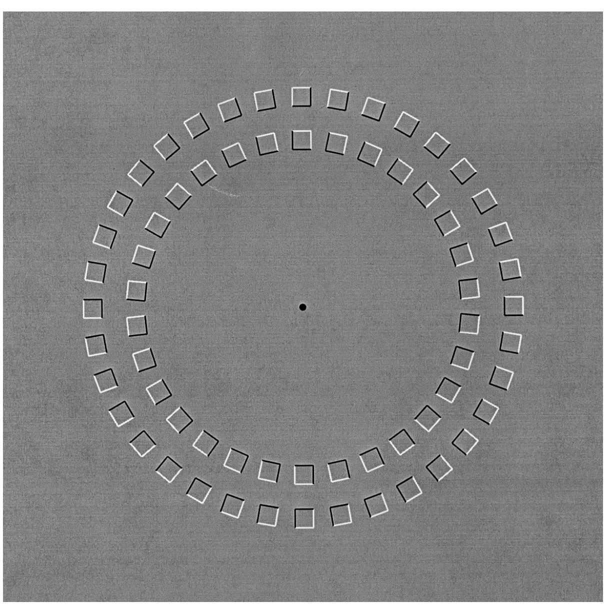

Fig. 2. Reversing the polarity reverses the sense of rotation, and of expansion/contraction.

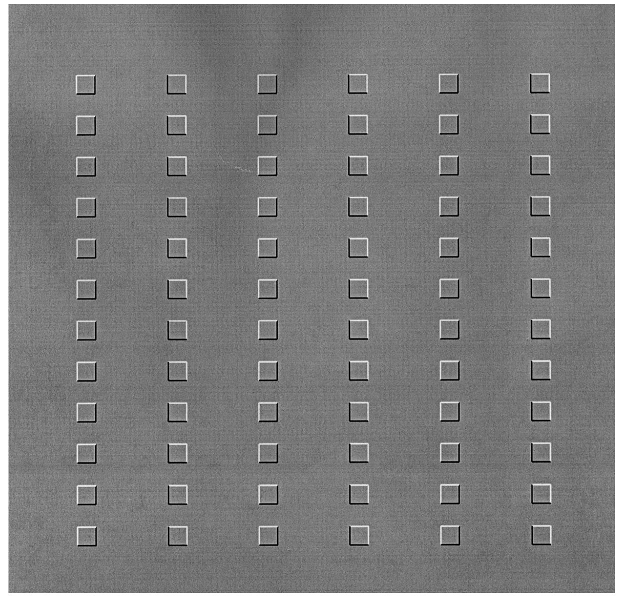

Fig. 3. Parallel columns of elements of opposite polarity show a motion shear on gentle horizontal shaking. A vertical shake produces a contraction/expansion of the gap between columns.

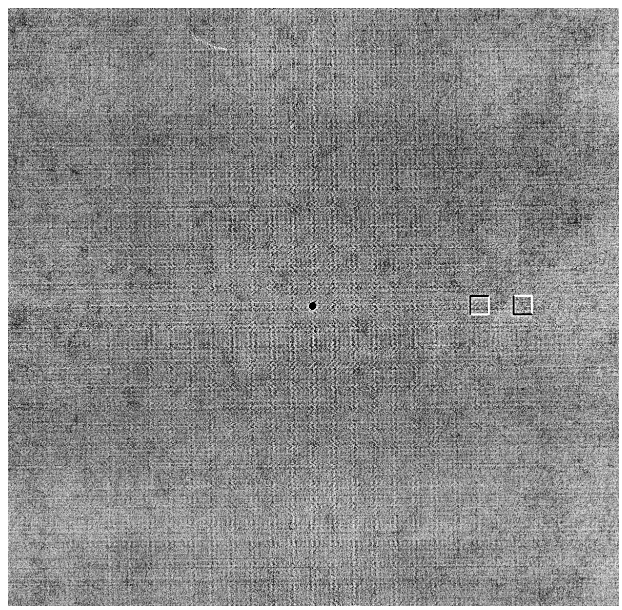

Fig. 4. In a limiting case, looming the dark spot can still elicit a relative motion between the two elements.

4. Orientation polarity

For the purposes of this work, we define an 'element' as any clump of lines that is spatially disjoint from the rest of the pattern and which is rendered through luminance contrast. (Informal attempts at isoluminant color rendering of our stimuli surprisingly (Ramachandran & Gregory, 1978) seem to retain the effect.) Here an element broadly corresponds to the 'texton' unit (Julesz, 1981) employed in investigations of human texture perception. Two types of orientation cues can instill 'polarity' to such an element. First, there are those cues rendered solely by the internal organization of luminance — such as the diagonal organization of the light and dark sides in our square element. Second, there are those cues of explicitly oriented form — such as the elements in Fig. 5. This latter example, shows how combining both types of cue leads to a somewhat stronger effect. (A lesser but still perceivable effect is achieved by simple black bars with no internal contrast — not illustrated here). In fact, elements of both types

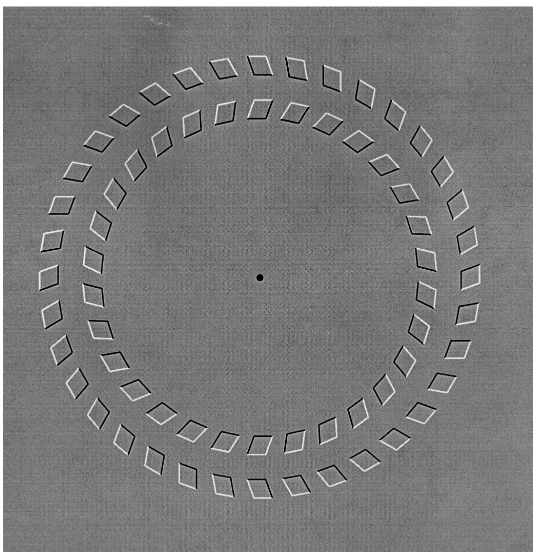

Fig. 5. Tilting the element of the concentric ring can heighten the sense of rotation.

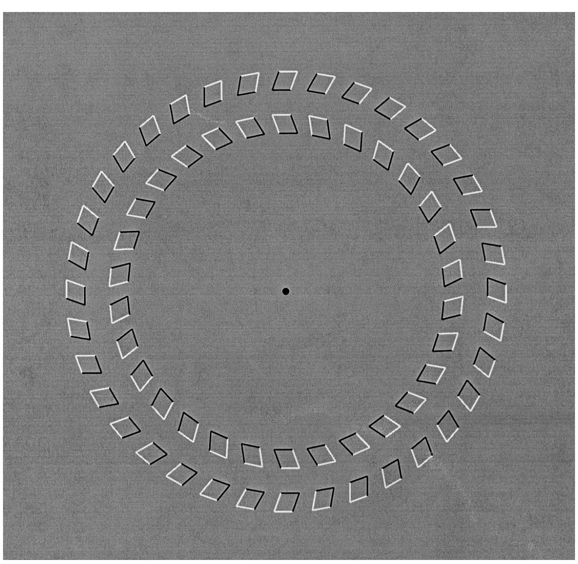

Fig. 6. Tilting them in the opposite direction can almost eliminate it.

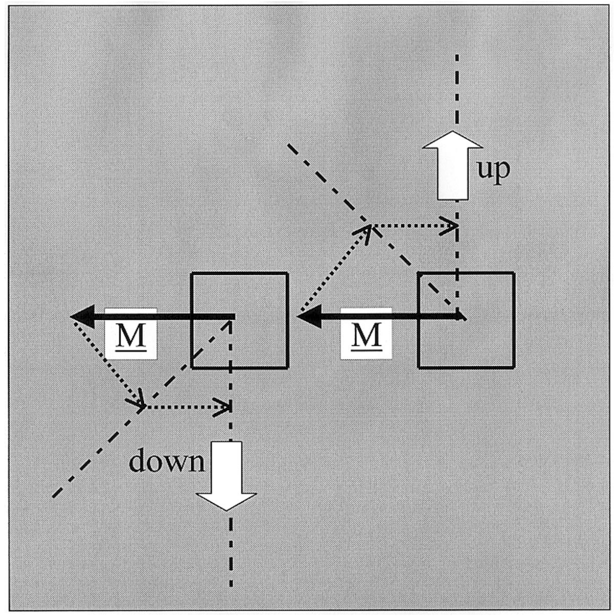

Fig. 7. Predicting the heading of illusory motion for our limiting case (Fig. 4): ***M*** marks the vector of the imparting velocity. This vector gets projected first onto the perpendicular of the dominant velocity and then in turn onto the line perpendicular to that which separated the centers of the participating elements.

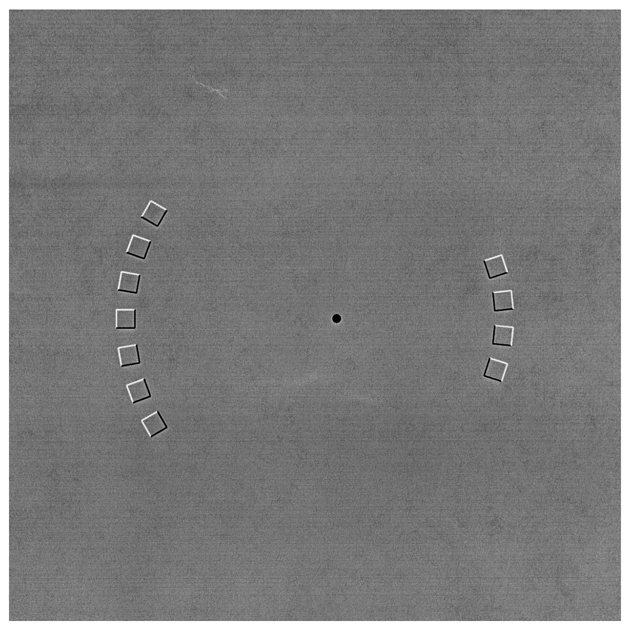

Fig. 8. Modifying any concentric circle stimulus so that only the left third of the inner circle and the right third of the outer circle are present eliminates the rotation.

exhibit dominant orientations in a local Fourier, receptive field sense (Adelson & Bergen, 1985). The dominant orientation of our square element is along its internal diagonal of asymmetry. Where dominant orientations align across different spatial scales the illusory effect can be reinforced — e.g. Fig. 5. When they do not align then the effect can be almost cancelled out — e.g. Fig. 6.

4.1. Apparent laws of the illusion

The motion that imparts the illusion is, in general, an instantaneous local spatial translation — be it horizontal, vertical, rotational or looming. The speed of the resultant illusory component appears to be roughly proportional to that of the imparting motion up to an upper bound where the motion blur destroys its visibility. Furthermore, the illusory component seems to obey additional geometrical constraints. These are most apparent in the limiting case Fig. 4. Firstly, its magnitude seems to be maximal when the imparting spatial translation is directed along the line that separates the centers of the two elements of a participating pair. Secondly, the magnitude seems to drop off to zero as the angle between these two vectors tends to 90°: there may be a cosine-like law. Thirdly, the magnitude seems to fall off as the separation distance gets either too small or too large: strong effects are achieved in an operating range of one to two element widths. Finally the heading of the illusory component (left/right, up/down) appears to be predictable as follows: (a) geometrically project the imparting velocity onto the line perpendicular to the element's dominant orientation; (b) then project the result onto the line perpendicular to that which separates the centers of elements of the participating pair. Thus we compute the left-most element in Fig. 4 to move down and the right-most to move up — see Fig. 7 — which appears to be the case for nearly all observers. Confirmation of this was provided by 15 subjects (all with normal vision) who were asked to indicate the direction of rotation (clockwise/counterclockwise) of the inner ring upon viewing (in randomized order) the spatial patterns shown in Figs. 1 and 2, while the background graylevel was set in a random sequence in the range: 10; 30; 50; 70; and 90% — where 0% corresponds to black and 100% to white. Mean viewing distance was 50 cm and naive subjects (newly familiarized with the effect in Figs. 1 and 2) were asked to loom each printed stimulus five times before reporting. In short, 179 out of total of 180 trials reported the direction of rotation according to the above prediction. (Just one subject on a single occasion reported no motion — at 10% gray.) In particular, these findings make it unlikely that the illusion is simply reflecting differences in absolute sensitivity to the displacement of luminance increments and decrements, as may be the case in a different illusion (Gregory & Heard, 1983).

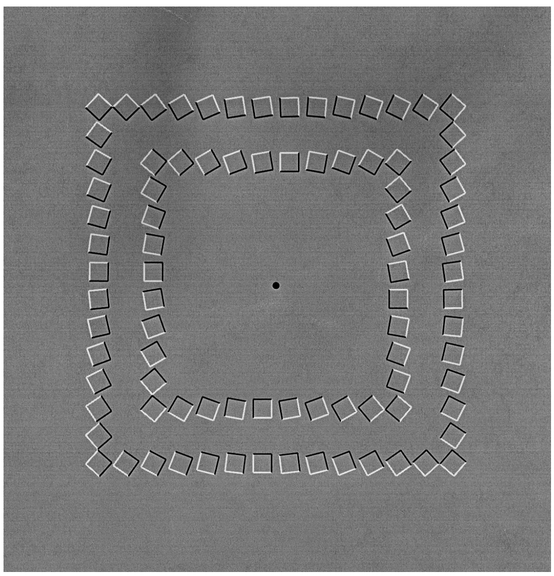

Fig. 9. The illusion persists on warping the concentric circles into concentric squares as long as the local form and characteristics of the constituent elements are preserved.

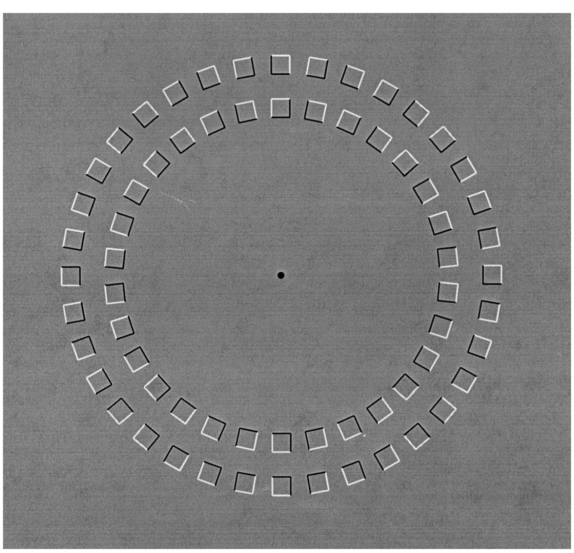

Fig. 10. Rendering stimuli such that neighboring pairs are of reversed polarity stops the illusory motion.

5. Discussion

An explanation for this illusion may stem from the fact that peripheral viewing is necessary to see it. Under peripheral viewing the precise spatial rectangular form of the pattern elements ought to be blurred and the dominant motion cues ought to derive, not from the constituent line sections, but from entire elements. In fact V1-type, motion selective units (Tolhurst &

Movshon, 1975; Adelson & Bergen, 1985) ought to respond to the antisymmetric diagonal polarity of each pattern element. We expect a maximal response by those units that are tuned to the spatial frequency matching one cycle of an element diagonally, and which are also oriented along those diagonals. For the purposes of motion estimation it seems that these maximal responses win out over any other non-maximal responses in the neighborhood such that each pattern element simply gets represented by the characteristics of the unit that best matches its diagonal. As such subsequent motion processing may only have access to the estimate made along the normal to that diagonal — a constraint akin to that known as the aperture effect (Marr & Ullman, 1981) by which, in the absence of other cues, a curve or line is perceived only to move normal to its tangent. (For lines or curves that constraint disappears when breaks or terminators are introduced. For our pattern elements the terminators at each corner — being viewed peripherally — have no such power: they are of too high spatial frequency to contribute.) Being able to measure motion only along the normal of the diagonal would help explain, for example, illusory rotation on looming Figs. 1 and 2. As the paper is moved closer, the induced motion of an element along its normal has both an expansive and a rotary component, and these may be considered separately (see Fig. 7). The expansive component is an expected natural consequence of looming so we seem to be able to interpret it as such and thus ignore it. By contrast, the rotary component has no such attributable cause and thus is available to generate an illusion of motion in the direction in which that component projects. Furthermore, switching contrast polarity ought to activate a different group of V1-type units, i.e. those tuned to the 180° opposite orientation, so the illusory motion would be, correctly, seen to reverse between Figs. 1 and 2.

Although the above discussion may explain how individual pattern elements receive a local illusory motion impetus, the question remains how these individual cues combine to the generate globally perceived rotation (Figs. 1 and 2), or translation (Fig. 3)? Our figures systematically place elements of opposite contrast polarity next to each other and thus facilitate an internal reference frame against which elements seem to flow. What flows against what seems, however, to be subject to several factors. In the case of concentric stimuli most observers experience the motion induction effect (Duncker, 1938) whereby the inner ring is seen to flow against a static outer ring. That effect is similar to what one experiences when one sees a train start to move through ones compartment window — the larger structure arbitrarily appears to be still while the other takes up all the relative motion. In fact, a frame drawn around some stimuli can also act as static reference, e.g. a single ring of element may be seen to slightly rotate even in the absence of the other. Many observers report both elements in the limiting case (Fig. 4) moving against each other, although some see only one move.

Debate (Heeger, 1987; Reichardt, Egelhaaf & Schlögi, 1988; Grzywacz & Yuille, 1990) reigns over the details of the mechanisms by which spatial context might actually be used to synthesize veridical 2D motion perception. In our stimuli however, a minimum useful spatial context would be a receptive field that spans pairs of elements. It is precisely over this spatial extent that our illusion emerges. Support for this arises by observing modifications of the stimuli shown in Fig. 1. Firstly, modifying our concentric circle stimulus so that only the left third of the inner circle and the right third of the outer circle are present — Fig. 8 — eliminates the rotation: thus no long-range pairing process seems to be in operation. Secondly, the illusion persists on warping the concentric circles into concentric squares — Fig. 9 — as long as the local form and characteristics of the constituent elements are preserved: thus local form cues appear to dominate over global ones. Finally, rendering stimuli such that neighboring pairs (around the circle — Fig. 10 — or down the column) are of reversed polarity stops the illusory motion: thus the effect cancels when a receptive field contains more than one pair if those pairs are of opposing polarity.

What we have termed orientation polarity is the defining attribute of the illusions shown here. A separate investigation — to be reported elsewhere — is investigating some illusory effects that this polarity can have on static patterns. Evident in the stimuli here are two such effects: (a) the altering of the bas-relief perception of each ring in Figs. 1 and 2 such that less than a quarter of the elements appear hollow, rather than the half that would be expected during standard conditions (Ramachandran, 1988); (b) the slight geometrical distortion of the perception of the rings in Figs. 5 and 6 from their true circular form and the columns in Fig. 3 from parallel.

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