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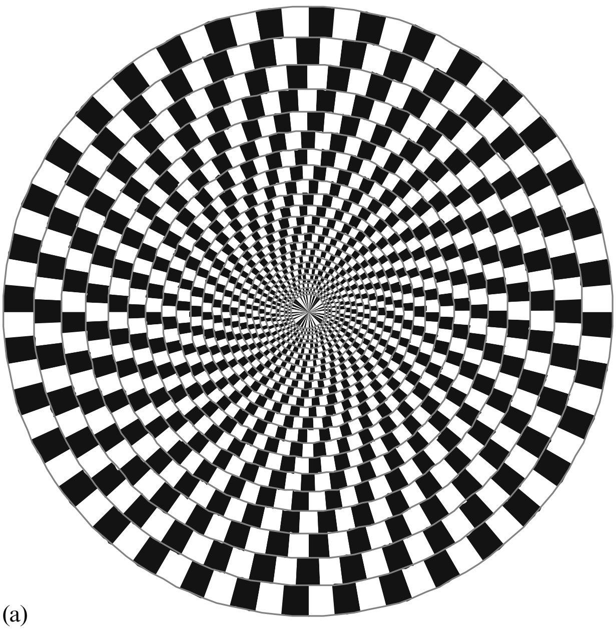
Last but not least

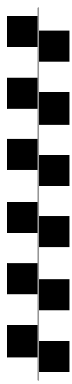
Abstract. New variations of the spiral illusion are demonstrated. They include spiral illusions of the Café Wall illusion and the Zöllner illusion, as well as other new orientation illusions. Thus the spiral illusion is not limited to the Fraser illusion. We discuss the role that detectors of spirals in a higher visual area might play in the spiral illusion.

New variations of the spiral illusion

Fraser (1908) presented a version of the twisted-cord figure, known as the Fraser illusion, in which observers perceive illusory spirals where only concentric circles occur. This paper demonstrates that the spiral illusion can be formed by other orientation illusions including the Café Wall illusion. Figure 1 shows an example of the spiral illusion of the Café Wall figure, in which gray concentric circles appear to be spirals when repetitive black-and-white bricks (or pie slices) are shifted by a quarter cycle. Indeed, the continuity between the Fraser illusion and the Café Wall illusion has been previously suggested (Fraser 1908; Morgan and Moulden 1986; Stuart and Bossomaier 1992).



(a)



(b)

Figure 1. (a) The spiral illusion of the Café Wall illusion, in which gray concentric circles appear to be spirals or appear to rotate clockwise toward the center. (b) A reference rectilinear version in which the gray vertical appears to tilt clockwise.

Many variations of the Café Wall figure including the illusion of shifted gradations and that of striped cords (Kitaoka 1998)—figure 2—can also form spiral illusions. Figure 3 presents two novel variations on this theme and their spiral counterparts. Figure 4 illustrates two variations built out of periodic repetitions of elemental units of pattern that we consider as limiting cases. They help clarify the common structural basis of the preceding figures and thus suggest a predictive hypothesis: that the spiral illusion will result whenever lines subjected to tilt distortion—such as in the Café Wall illusion—are converted into concentric circles.

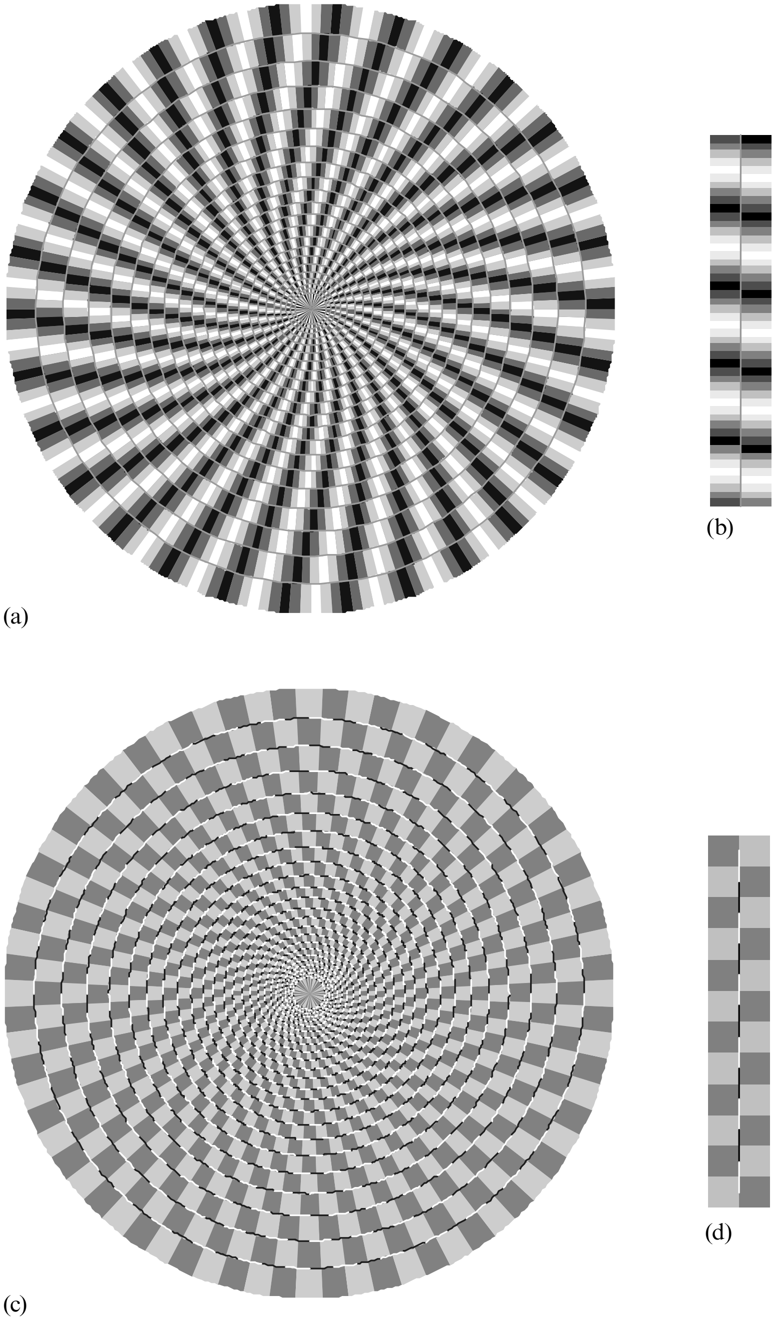


Figure 2. (a) The spiral illusion produced by shifted gradations, in which gray concentric circles appear to be spirals or appear to rotate clockwise toward the center. (b) A reference rectilinear version of (a) where the gray vertical appears to tilt clockwise (Kitaoka 1998). (c) The spiral illusion produced by striped cords, in which striped concentric circles appear to be spirals or appear to rotate clockwise toward the center. (d) A reference rectilinear version of (c) where the striped vertical appears to tilt clockwise (Kitaoka 1998).

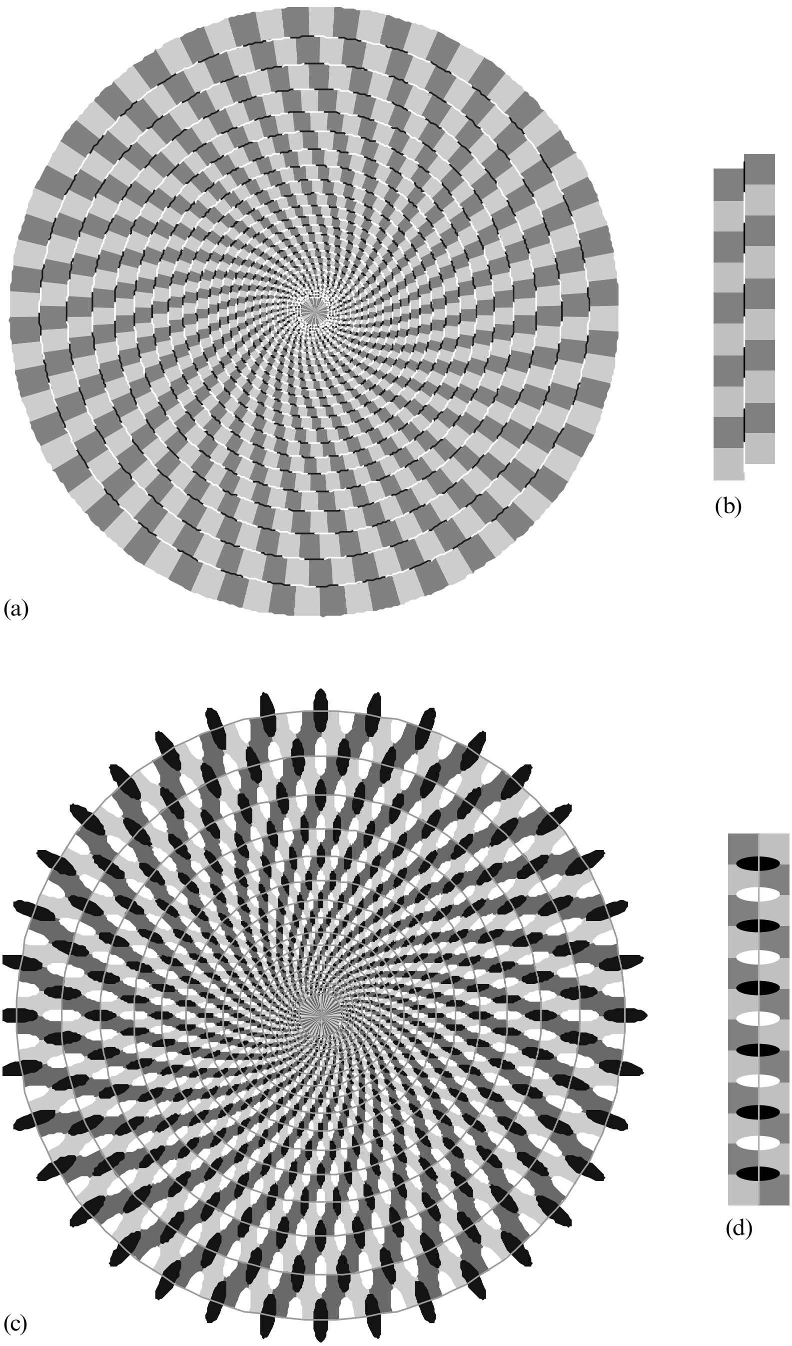


Figure 3. (a) The spiral version of the reverse Café Wall illusion of striped cords, in which striped concentric circles appear to be spirals or appear to rotate clockwise toward the center. (b) A reference rectilinear version of (a) where the striped vertical appears to tilt clockwise. (c) The spiral version of the illusion of black-and-white ellipses, in which gray concentric circles appear to be spirals or appear to rotate clockwise toward the center. (d) A reference rectilinear version of (c) where the gray vertical appears to tilt clockwise.

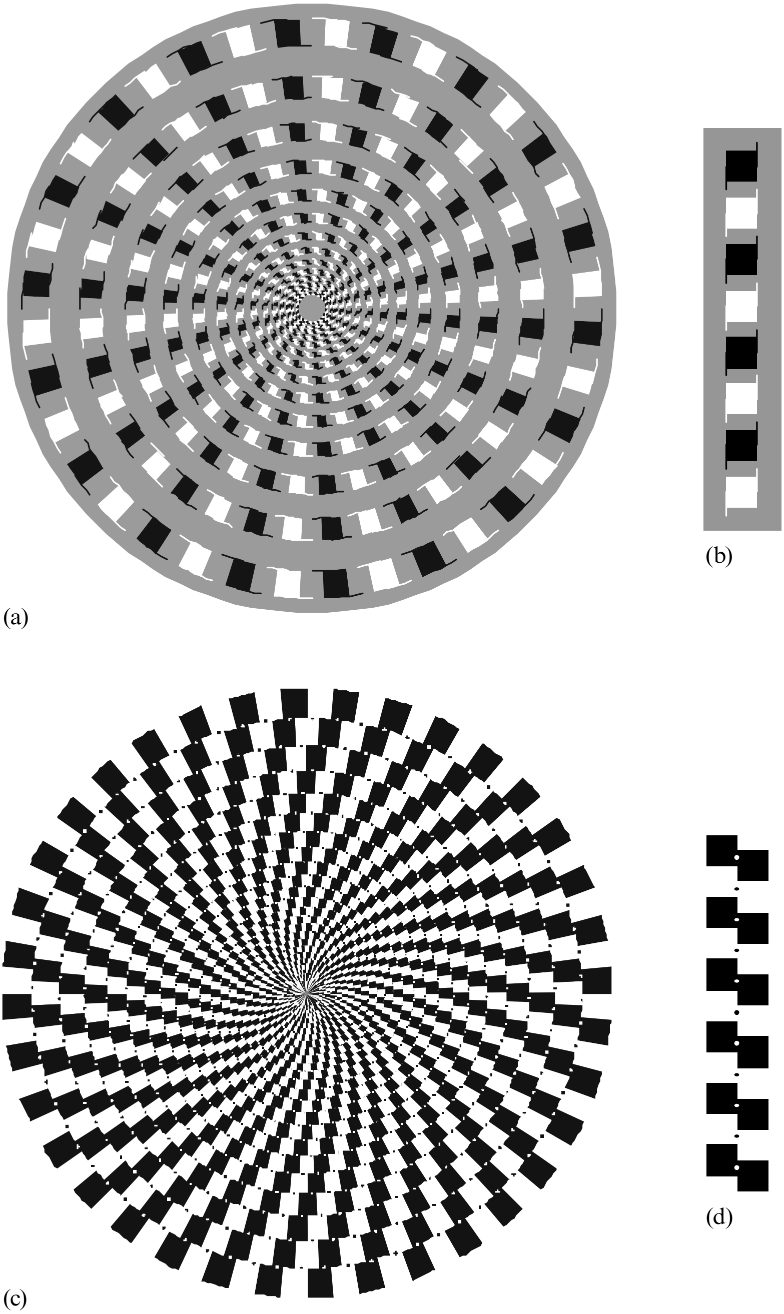


Figure 4. (a) The spiral version of a limiting case of the Café Wall illusion, in which concentrically aligned units appear to be spirals or appear to rotate clockwise toward the center. (b) The rectilinear version of (a) in which both vertical sides of the units appear to tilt clockwise. (c) The spiral version of a dot-rendered limiting case of the Café Wall illusion, in which concentrically aligned dots appear to be spirals or appear to rotate clockwise toward the center. (d) The rectilinear version of (c) in which the vertical dot column appears to tilt clockwise.

To explore this further, we rolled the Zöllner figure (an acute-angle expansion illusion) into concentric circles. Figure 5 illustrates two of the resulting spiral illusions. Although the rectilinear Zöllner illusion can render large effects (figures 5b and 5d) (Morinaga 1933; Wallace and Crampin 1969; Oyama 1975), our spiral version appears to be a relatively weak illusion. Indeed, in informal tests, some observers did not report

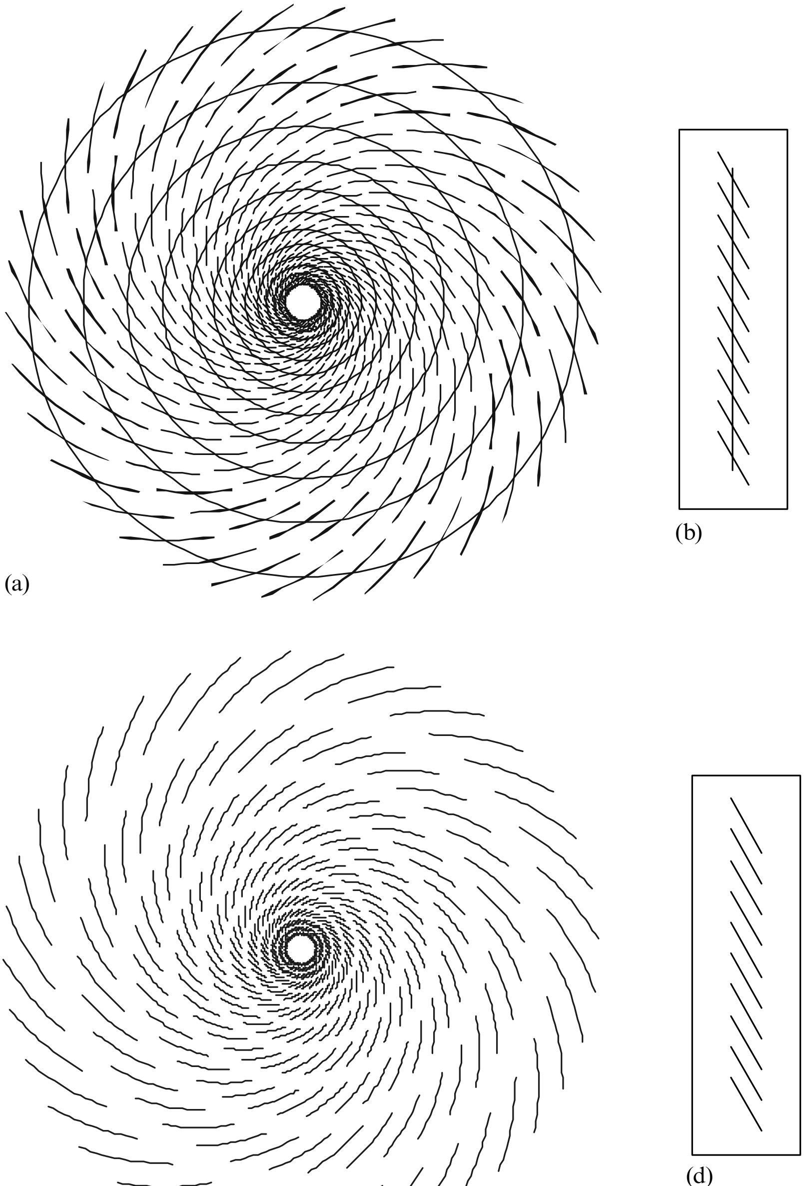


Figure 5. (a) The spiral version of the Zöllner illusion, in which concentric circles appear to be spirals or appear to rotate clockwise toward the center. (b) The rectilinear version of (a) in which the vertical line appears to tilt clockwise. (c) The spiral version of illusory contours, in which concentric illusory contours appear to be spirals or appear to rotate clockwise toward the center. (d) The rectilinear version of (c) in which both vertical illusory contours appear to tilt clockwise.

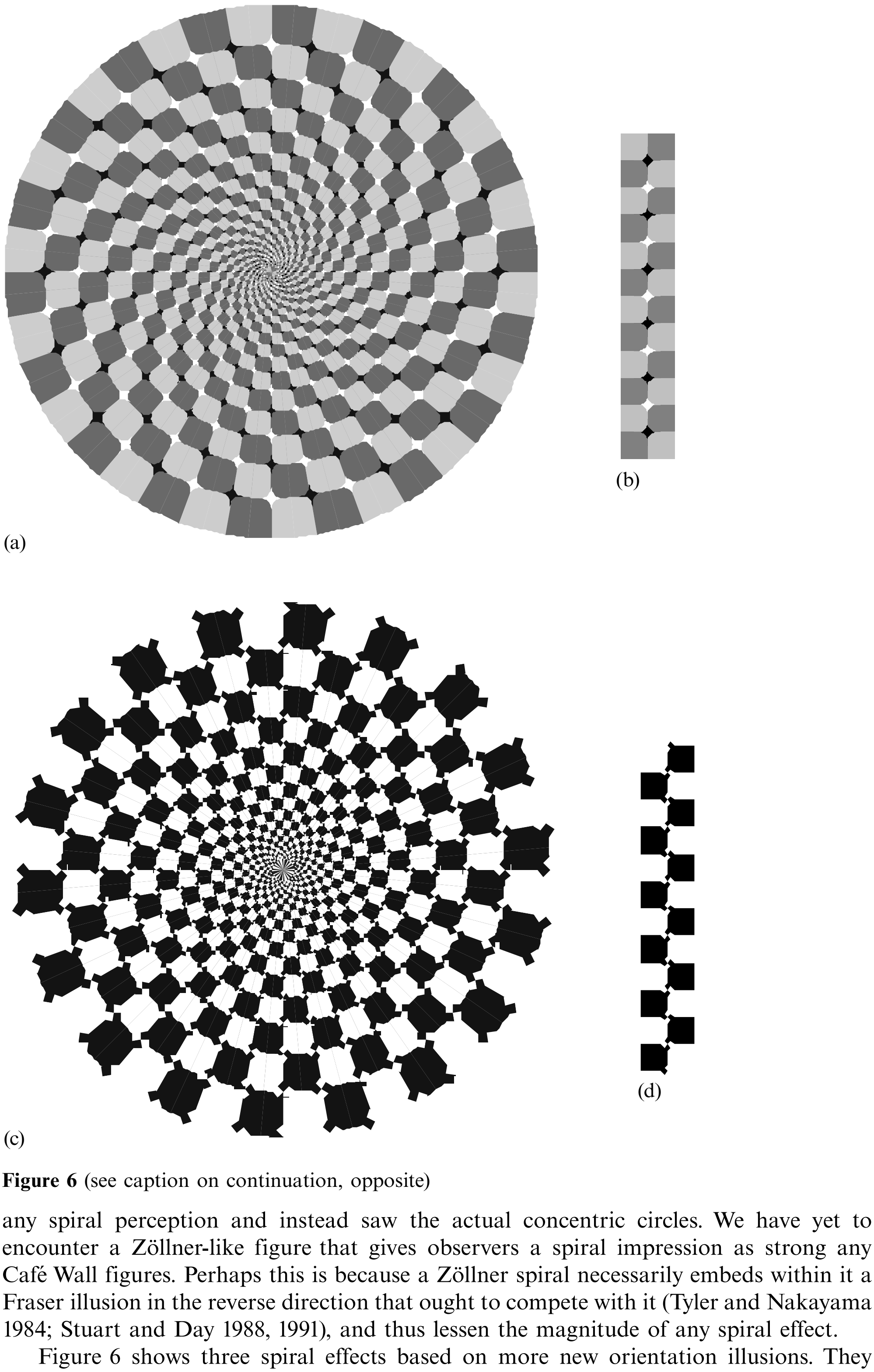
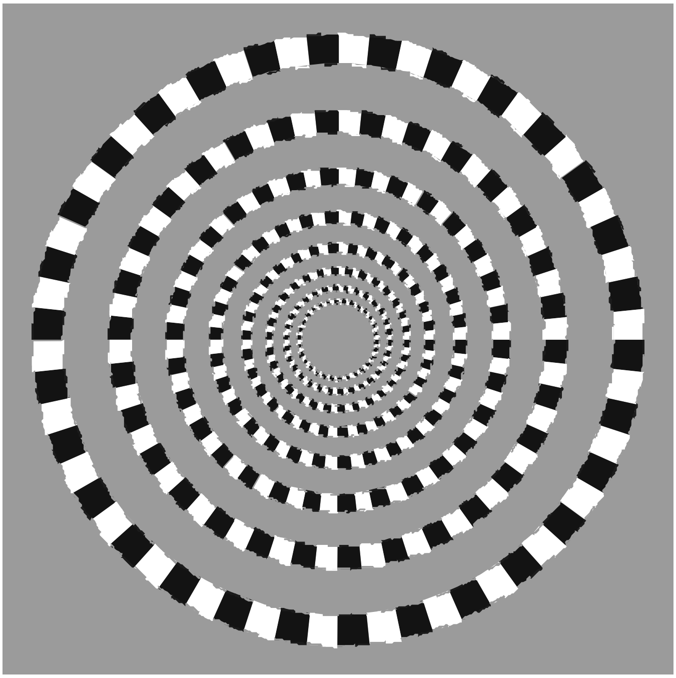


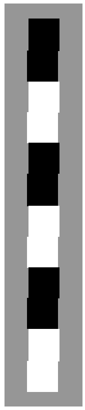
Figure 6 (see caption on continuation, opposite)

any spiral perception and instead saw the actual concentric circles. We have yet to encounter a Zöllner-like figure that gives observers a spiral impression as strong any Café Wall figures. Perhaps this is because a Zöllner spiral necessarily embeds within it a Fraser illusion in the reverse direction that ought to compete with it (Tyler and Nakayama 1984; Stuart and Day 1988, 1991), and thus lessen the magnitude of any spiral effect.

Figure 6 shows three spiral effects based on more new orientation illusions. They all give a strong spiral impression, again supporting our hypothesis. Other examples



(e)



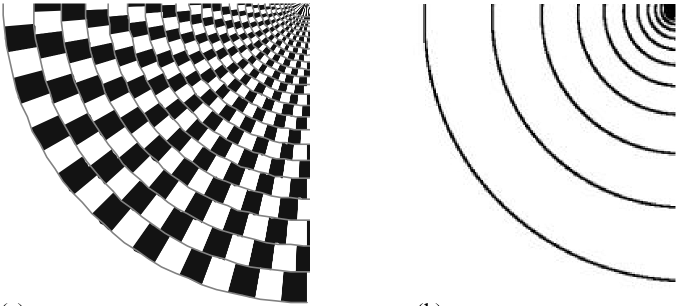
(f)

Figure 6 (continued). (a) The spiral version of the new illusion of 'Y-junctions'. (b) The rectilinear version of (a) in which the middle line appears to tilt clockwise from the vertical. (c) The spiral version of the new illusion of 'fringed edges'. (d) The rectilinear version of (c) in which the vertical column appears to tilt clockwise. (e) The spiral version of the new illusion of 'shifted edges'. (f) The rectilinear version of (e) in which that the vertical column appears to tilt clockwise.

of this kind include those presented by Cowan (1973), Popple and Levi (2000), and Popple (personal communication) who developed a second order Zöllner spiral induced by contrast-modulated carriers.

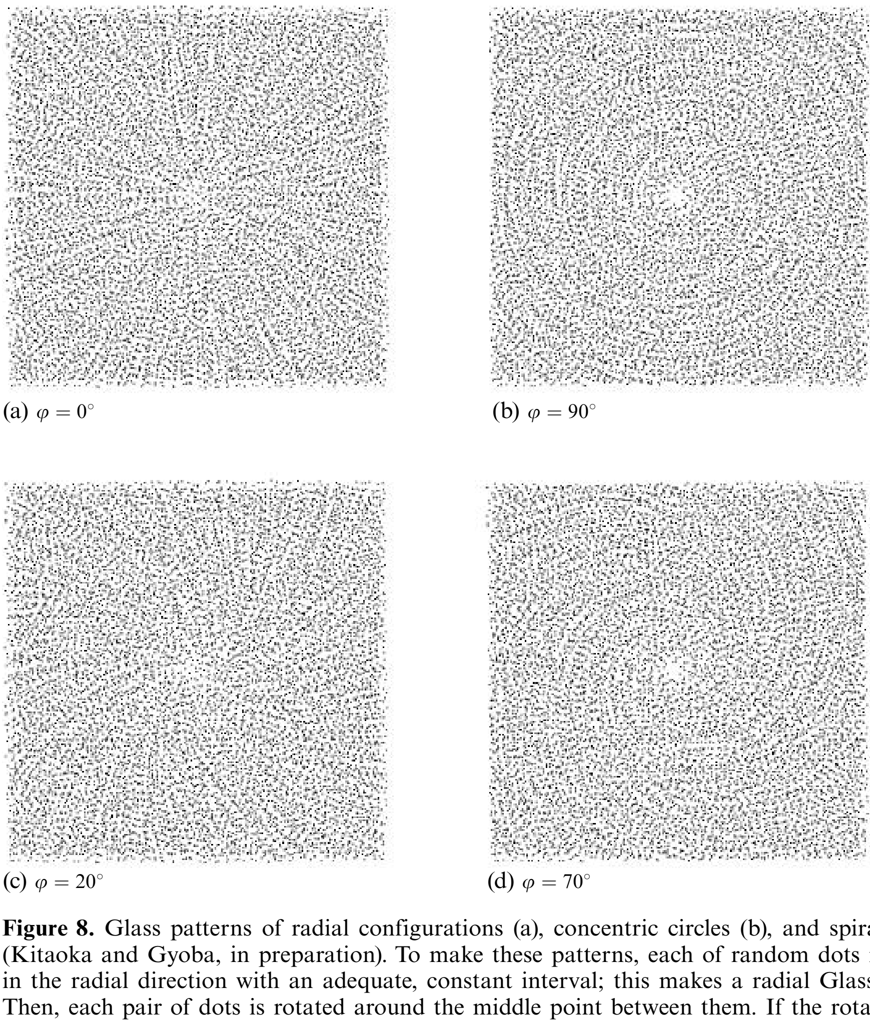
We now discount, in turn, two possible structural explanations for the spiral illusion. The first is that global luminance spirals (eg black-and-white stripes in figure 1a) produced by the transformation into curved polar format could contribute to the spiral illusion. An indication that this is not so is the observation that the direction of global luminance spirals of figure 3a is the reverse of that of figure 1a, yet the directions of illusory spirals are identical. This explanation was also discounted by Cowan (1973) who examined several variations of the Fraser illusion. Furthermore, there is a class of figures that shows no global luminance spirals (figures 4a and 6e), which nevertheless produce the spiral illusion. We therefore suggest that global luminance spirals make little contribution to the spiral illusion.

A second possible explanation might be that the mere act of transforming the stimuli from rectilinear into curved polar format causes a distortion to the constituent elements at a local level and that this then produces the impression of a spiral. In this case, however, one would expect even a partial concentric figure to generate a similar impression, yet it does not. This is well illustrated in figure 7a that plots only the lower left quarter of the stimulus from figure 1. In fact, real spirals do not even produce an impression of a spiral when they are partially plotted in the same way—see figure 7b.



(a) (b)

Figure 7. The lower-left quarters of (a) the Café Wall spiral figure (figure 1a) and (b) a real logarithmic spiral (figure 9a). Although the arcs in both appear a little distorted, neither figure gives much impression of being part of a spiral.



(a) $\varphi = 0°$ (b) $\varphi = 90°$

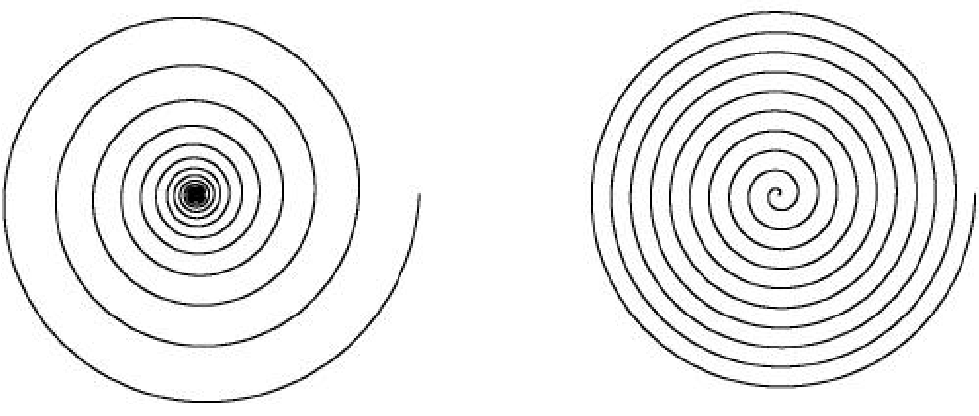
(c) $\varphi = 20°$ (d) $\varphi = 70°$

Figure 8. Glass patterns of radial configurations (a), concentric circles (b), and spirals (c and d) (Kitaoka and Gyoba, in preparation). To make these patterns, each of random dots is duplicated in the radial direction with an adequate, constant interval; this makes a radial Glass pattern (a). Then, each pair of dots is rotated around the middle point between them. If the rotation angle φ is 90° the figure is a circular Glass pattern (b). When φ is between 0° and 90° the figure is a spiral Glass pattern. Examples are shown: $\varphi = 20°$ (c) and $\varphi = 70°$ (d).

Perhaps, then, the spiral effect is a consequence of a mechanism that fires a unitary spiral detector—in our case erroneously. There is cumulative evidence for detectors of non-Cartesian receptive-field organization in the extrastriate visual cortex or area V4 (Gallant et al 1993; Gallant et al 1996; also see Wilson et al 1997; Wilson and Wilkinson 1998). These non-Cartesian forms included polar (concentric and radial), hyperbolic, and spiral gratings, and Gallant et al (1993) showed a cell that responded better to spiral patterns than to any concentric or radial pattern. This finding adds plausibility to the existence of the detector of spirals.

From a geometrical point of view, spirals can be thought to have continuity with polar figures such as concentric or radial patterns: a concentric pattern consists of local lines whose orientations are orthogonal to virtual lines from the center, while a radial pattern consists of local lines whose orientations are the same as those of virtual lines. When the angle φ formed by local lines and virtual lines lies between 0° (radial) or 90° (concentric), spirals appear. This is illustrated in figure 8, in which Glass patterns (Glass 1969) can be perceived as spirals in addition to the usual concentric or radial interpretations (Kitaoka and Gyoba, in preparation). Here the perceived spiral is thought to be the logarithmic (Bernoulli) spiral (figure 9a)—also known as the equiangular spiral since the angle φ formed by the tangent line of a particular point and the line drawn from the center is constant in this spiral (cf Archimedes's spiral shown in figure 9b). Illusions that induce an equiangular tilt to each element that is placed on concentric circumferences ought to produce the perception of logarithmic spirals.

In summary, the new variations of spiral illusion introduced here suggest that perceived spirals result whenever lines producing tilt illusions in a coherent direction are converted into concentric circles. Moreover, we suggest that there might be detectors of logarithmic spirals in the extrastriate visual cortex and these detectors might collect information from induced local tilts, resulting in the misperception of the spiral illusion. This would accord with the notion of a collector unit (Morgan and Hotopf 1989) and with the notion of a second-order orientation unit (Morgan and Baldassi 1997).



(a) $r = \exp(0.05\theta)$ (b) $r = \theta$

Figure 9. Examples of two types of spiral. (a) Bernoulli's spiral (logarithmic spiral or equiangular spiral). It is given in polar coordinates (r, θ), $r = a\exp(k\theta)$, where a and k are constants. Note that $k = 1/\tan\varphi$ ($0^\circ < \varphi < 90^\circ$). (b) Archimedes's spiral, which is given in polar coordinates (r, θ), $r = a\theta$, where a is a constant.

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