Perceptual Disruption and Composure in Bridget Riley’s *Fall*

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Riley explores the thrill of visual sensation.
—Tate Gallery, London

This bold caption [1] accompanied Bridget Riley’s work *Fall* in the permanent collection of the Tate Gallery, London. Created during an exceptionally innovative period in Riley’s career, *Fall* (Fig. 1) exemplifies 1960s Op artists’ abstract expression of tension between mental composure and disturbance. A seemingly intractable fluctuation of visual patterns emanates from this simple arrangement of curves. Yet despite the apparent simplicity of her work, Riley’s artistic process [2] involves numerous trials before a composition of the desired tension and subtlety is created, suggesting that a deeper order might govern its visual simplicity.

The artistic merit of Riley’s work and that of other Op artists came under fire initially, with their art being described as mechanistic optical trickery intended to maximally disrupt natural perception [3]. Here I present a scientific report of previously unremarked structural order in *Fall*, in an attempt better to understand the significance of Riley’s exploration of visual sensation and suggest why trivializing this art is premature.

**Transient Apparent Contrast**

Any scientific statement regarding structural order in a painting requires an objective reconstruction of the perceptual structure of the experience of creating and viewing that artwork. While it is impossible to capture the entirety of this work by any process of decomposition, key elements of visual percepts in the case of *Fall* may be analyzed by focusing on the effect of visual effects associated with black-and-white line patterns. While a multitude of perceptual phenomena, such as subtle shifts in 3D appearance, faintly colored rainbows and local deformations are all experienced when viewing periodic line images [4], arguably the most salient effect is the appearance of dynamically shifting regions of transitory apparent contrast [5]. These variations in apparent contrast accompany the slightest change in the spatial relationship of the observer relative to the painting [6]. Here I focus on understanding the perceptual structure related specifically to transitory apparent contrast.

Purkinje [7] was among the first scientists to report what appeared as shimmering strips of high contrast in dense black-and-white etchings by Dürer. Helmholtz [8] elaborated these observations into an early account of transitory apparent contrast, claiming that optical deformations during adjustments in the lens of the eye distort the image falling onto the retina by differentially blurring different image regions. The phenomenon has since been investigated widely in vision research, with some resulting consensus that the effect is due to the inability of low-level neural mechanisms to deal with rapid changes in the amount of light reaching the eye [9] and that relative displacements such as eye movements elicit the strongest effect [10]. MacKay [11] explained observed contrast effects as patterns created when the image registered at a given moment interferes with the
afterimage of a previous, very similar version of that same image, which occurrence is known as a moiré effect [12]. According to this explanation, transitory apparent contrast should appear as periodic patterns of high and low contrast, like richly grained wood, or the banded moiré patterns observed when two thinly woven cloths overlap. However, recent computational advances [13] based on visual transduction dynamics [14] of the cones in the macaque monkey retina show that perceived patterns of transitory contrast are very sparse, appearing like singular ribbons of high contrast instead of richly banded moiré patterns. As opposed to moiré effects, the observed sparse loci of high contrast are accurately predicted to occur at locations where the illumination reaching each photoreceptor changes sufficiently slowly [15]. Note that the transitory contrast described here occurs with relative displacement between stimulus and observer, such as when the observer moves in front of the painting.

Even if the salient variations in apparent contrast in Fall may seem intractable when casually (and randomly) inspected, the order inherent to the spatial location of the apparent contrast variations can be readily demonstrated by turning Fig. 1 clockwise and counterclockwise in quick succession (rotation), or by rapidly moving closer and further away (scaling) or up and down (translation). (Hint: Grip the page firmly with both hands and repeat movements as steadily and quickly as possible to enhance the described effect. The page should be held flat, and should not bend while it is moved.) Each configuration of relative displacement elicits a unique but repeatable set of contrast loci (i.e. regions appearing like thick curved ribbons of high contrast) similar to the computational predictions derived using a model of visual transduction in retinal cones (Color Plate B No. 1). The loci appear where local segments of the painted stripes are effectively stationary relative to the retina [16], given the configuration of the motion vector field imposed by rotation, scaling, etc. The level of order in observed contrast effects is therefore directly coupled with the degree to which movements of the observer are ordered. In addition, the observed contrast patterns are distinctly different from a moiré pattern.

Computational snapshots shown in Color Plate B No. 1 were obtained [17] for very simplistic and above all regular and repetitive displacement configurations. In a real situation (i.e. in viewing a painting in a gallery), the relative displacement when a human onlooker views the painting will be affected by changes in body posture combined with head and eye movements. The resultant displacements are therefore complex combinations of rotation and scaling around different geometric centers, translation, perspective deformations and so forth. The perceptual structure of actual transitory contrast loci is therefore much more intricate and dynamic than the demonstrated simulation snapshots of Color Plate B No. 1 imply. Figure 2 shows simulated contrast loci at four different intervals along a hypothetical sequence of displacements when a human onlooker views the painting while shifting her weight from one leg to the other. Contrast loci undulate through completely different structural configurations even for this limited movement and should seriously affect perceptual grouping of the compositional elements viewed in the painting.

**A SOURCE OF PERCEPTUAL DISRUPTION**

The perceptual tension experienced in Fall explicitly depends on the curves of the actual composition. As the observer gazes over the painting, greater visual effort is required to scan the shape of the stripes properly owing to the increase of curvature as the lines become compressed toward the bottom. As the lines become more densely packed around deflection points, greater visual concentration is required to maintain a fixed gaze on the traced line. In fact, experiments with line images have shown that the resulting visual tension causes erratic eye movements [18].

Not surprisingly, the persistent presence of shifting contrast loci, in addition to an already visually taxing setting, further disrupts normal effortless perception of the composition, due both to the dynamic nature of the contrast loci in themselves and to the fact that the shapes of contrast loci never match those of the painted lines. High contrast loci depend strongly on the center of displacements, such as rotation and scaling, implying that for any change in observer position or eye movement, the salient contrast pattern changes shape and shifts to a new location. Yet the clarity of these loci appearing in peripheral vision presents the visual system with a nearly irresistible cue for fixation. Hence, subjects almost certainly try to fixate and scrutinize peripheral parts of the observed contrast loci, only to find that it completely regroups upon any gaze shift. Figure 3 shows how a contrast locus changes shape when fixated at three different image locations during straight motion orthogonally toward the surface of the painting.

As seen in Color Plate B No. 1, simulated loci of high contrast (corresponding to the blue ribbons in each panel) range from one or more gentle curves at the top of the figure to sharp, closely spaced fragments at the bottom. Clearly deviating from the geometry of actual black-and-white stripes, the transitory occurrence of contrast loci may thus interfere with the unhindered perception
of stripes. Theoretically [19], the actual shape of contrast loci will only match that of the actual lines in the painting when the configuration of displacement exactly matches the structure of the painted lines. Since this situation cannot be physically actualized, contrast loci will always deviate from the actual painted stripes. Conflicting candidate perceptual wholes will thus always arise, becoming a source of perceptual rivalry. Visual brain mechanisms tend to simplify visual signals by grouping closely spaced lines into textural surfaces—a phenomenon known as crowding [20]. Here, the observed contrast effect (dependent on active, nonstationary exploration) directly opposes this function in the form of a narrow locus of line segments that break away from the more simplistic grouped line texture.

Transitory apparent contrast, and hence the source of visual disruption, can be dramatically reduced by lowering the luminance contrast of Fig. 1. Visually sophisticated observers deemed the painting less visually interesting when viewed at low contrast. Hence one can informally conclude that the disruptive effect is at least a necessary (but not sufficient) condition for the visual appeal of the artwork [21].

PERCEPTUAL COMPOSURE AND STABILITY

Riley is known to have been deeply inspired by the natural scenery of Cornwall [22]. She explains that her work is intended to re-create the experience of looking at nature and especially how active vision seems to move over details and the kind of visual situations it encounters. One can argue that Fall differs from typical mechanistic experimental line stimulus patterns in the sense that it appears more subtly nuanced and “natural,” but can this statement be assessed objectively?

Natural scenes viewed in normal visual conditions usually constitute a global structural framework within which perceptual brain mechanisms can relate the distribution of increasingly finer spatial details [23]. For example, fractal patterns are organized in such a hierarchical self-similar manner. Experimental findings show that humans perceptually function more effortlessly in a fractal visual environment, bearing testimony to the fact that our visual systems have evolved in a natural world filled with self-similar patterns [24].

Riley’s work might seem far removed from the world of fractals. Patterns of densely packed lines do not evoke the self-similarity intuited in naturalistic structures. To the contrary, they elicit erratic eye movements, possibly because periodic lines lack, or obfuscate, any global structural framework that would otherwise provide cues about the position of fine details in relation to larger image structure. Fall may therefore provide an ideal medium in which to launch a severe “assault on the retina” [25].

Closer scrutiny of simulation results reveals evidence to the contrary. In addition to perpetual fluctuations of transitory contrast loci, whenever any movement is initiated, a large triangular region of low contrast appears around the center of the canvas (the reddish cen-
When we realize that this invariant structure may constitute a spatial frame of reference during visual exploration of the painting, the cause of this structure becomes significant. Riley meticulously designed the composition of Fall before handing it to studio assistants to be accurately painted, by hand, in acrylic [26]. The distribution of small deviations introduced through painting by hand can be tested by comparing Fall with a nearly identical facsimile crafted on a computer by repeatedly copying just one identical black-and-white line pair from the original painting over the entire computer screen. The resulting image appears unarticulated and actually more optically disruptive than the original painting (Fig. 4). If Riley intended simply to disrupt perception, she could almost certainly have opted for such a mechanistic means of image reproduction. It is interesting to note that commercial reproduction of her designs on fabric for clothing and furniture succeeded in little more than mechanistic instances of her original designs, much like Fig. 4.

The underlying differences between the original painting and its computer facsimile can be demonstrated by comparing their global structure, in the form of low spatial frequencies (Figs 5a and b). While the facsimile has only horizontal bands (Fig. 5b), the original is highly articulated (Fig. 5a), appearing like a cusped flame that breaks up toward the upper half of the canvas. Smaller sections within the triangle resemble the shape of the flame in its entirety and thus approach self-similarity, not unlike the fractals of nature. Fractal analysis using the Fourier power spectrum [27] indicates that the flame has a fractal dimension of about 1.35 (compared to 1.02—nearly one-dimensional—for the facsimile), with a high degree of statistical self-similarity, that is, adherence to an inverse power law paradigm.

This observation underscores the difference between active and passive viewing. Without any relative movement between the observer and Fall, the cusped flame is not salient, but the actual line pattern dominates. Its periodicity constitutes a non-fractal pattern (i.e. its Fourier spectrum significantly deviates from the inverse power law). During active exploration of the painting, however, retinal filtering on behalf of the observer increases perceptual salience of the cusped triangle, so that now the visual system is engaged with an intrinsically inverse power law pattern. In this sense, the present study suggests that spectral analysis of art [28,29] should benefit from consideration of perceptual structure of actively viewed compositions. This distinction would greatly influence any conclusions about the extent to which Fall (and possibly many other paintings) adheres to the inverse power law observed in natural scenes, not to mention the observer’s share in the effective image statistics of natural scenes in themselves.

Triangular composition is a classic technique in Western art [30], and can be placed so as to ground the painting [31]. Here, the triangular motif is highly abstracted and functions as a hierarchical structural framework that visually anchors perception of relations between compositional elements at varying spatial scales during fleeting moments of active visual exploration. It is embedded in small fluctuations in painted line width that become subliminally salient during relative displacement, since motion induces blurring, in effect enhancing low spatial frequency structure by canceling out the finer spatial details. In effect, finer black and white details are averaged (blurred) during movement, leaving a neutral grey ground on which the low spatial frequencies of the triangular region then appear more salient. Accidental fluctuations due to painting by hand should be evenly distributed across the canvas. However, analysis of line width reveals that the painting is divided into three distinct regions (Color Plate B No. 2), consisting of a central band where dark lines are slightly wider than average, plus the areas on either side of the central band, where white lines are wider than average. If these deviations were simply the result of systematic erroneous shifts of a stencil, or a function of angle and distance of the hand of the painter relative to the edge of the canvas, both white and black lines would have undergone the same deformation, gradually increasing with distance from the edge of the canvas and not necessarily symmetrical around the center of the painting. Yet this is clearly not the case, as the regular, nonoverlapping black-and-white line regions show. Along the width of the painting, the global composition is divided into three evenly spaced columns. Along the vertical dimension of the canvas, line width appears to have been modulated to accentuate the triangular flame-like cusps of the central region. It is tempting to conclude that the subliminal abstract order in the painting is the result not of erratic hand painting but of intentional design. Here, I equate intentionality not with premeditated design but with a high degree of sensitivity to the perceptual impact of a composition while it was being created. In this sense, intentional visual effects evolve continuously, involving (certain) artists at all stages of design and painting, until the artwork reaches a stage at which it appears complete and “feels right.”

**DISCUSSION AND CONCLUSION**

Artistic understanding and scientific analysis of abstract art are becoming increasingly complementary [32,33]. The present analysis aims to contribute to art and science dialogue by providing snapshots of ephemeral compositional layers associated with a classic Op art painting.

Perceptually, great works of art seem to be “just right,” as their longevity and continued appreciation prove. Still, it remains difficult to explain why and how some works are “great” while others that have roughly similar components and subject matter somehow strike us as less interesting. Here, underlying organization of the visual effects experienced in Fall forms the core of the scientific investigation of its lasting attraction.

Op art is noted for and sometimes equated with hallucinatory and illusory effects that are implicitly associated with disruption of normal visual perception. With access to mechanical means of image reproduction, Riley could have opted for a geometrically perfect composition that would maximally “attack the senses.” Instead, Riley seemed intentionally to use fluctuations of the visual field...
as a medium in which to present richly articulated, contra-structured compositional layers that drive the perceptual tension and subtly experienced in works such as Fall. In actuality, the design of the curved lines themselves is based on natural form, having originated from sketches with the moving human form in mind [34] and intentionally painted by hand to avoid mechanical repetition. The painting thus appears far richer in perceptual effects than a similar computer-generated facsimile or a typical line stimulus used in experimental vision research. Scientists have noted the complexity of effects in Fall, and on various occasions have chosen the painting as a centerpiece for scientific investigations into contrast illusions [35]. Ironically, scientists have throughout effectively cancelled the subtle effects of the original painting by opting for mathematicaly generated stimuli in which all the lines are exactly identical, similar to Fig. 4, and thus devoid of the global structure revealed in Fig. 5a.

Many questions regarding art are difficult to address scientifically. One could ask, “Why create Op art at all?” and in the case of Fall, “Why in this specific form?” [36] Based on the findings presented here, one may speculate that the deep complexity underlying even the apparently mechanistic Fall bears upon the insight that nature abhors exact repetition: Its complexity cannot be “modernized,” but permeates even the most rigid construct, endlessly breaking up, flowing together, a continual combustion and release of energy. Indeed, Riley explores the thrill of visual sensation and far beyond.

Acknowledgments

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Glossary

counterpoint—a curved, ribbon-like region appearing at high contrast, seen when moving a stimulus image consisting of black and white lines. The shape of the counterpoint will not be the same as the appearance of the actual black and white lines.

eoveate—to bring a visual cue into the center of one’s field of vision by an appropriate eye movement.

inversion line law—if variables A and B are related by power C, such that A = (B)^C (comment: i.e. A is equal to B raised to the power of C), and C > 0, then A and B are related through an inverse power law, that is, for any untrusted value of B, A will decrease as a negative power of B. A well-known example is the amplitude of the Fourier Power Spectrum of a natural image, which decreases as the inverse power of the spatial frequency in the spectrum.

perceptual grouping—grouping of simple visual cues such as line elements into larger meaningful wholes or forms.

perceptual rivalry—fluctuation of the perceived figure of attention, between different possible plausible grouping configurations for the visual cues presented.

transitory apparent contrast—high contrast appearing at some regions within a stimulus image whenever the spatial relations between the observer and stimulus change, such as when the observer moves toward the stimulus. Note that even if physically measurable contrast across the image is uniform (for example, the black and white lines in Fig. 1 of this paper have the same contrast everywhere), its apparent, or perceived, contrast could appear to differ vastly at different locations.

visual transduction model of a retinal cone—mathematical description of the relationship between the amount and rate of incident light projected onto a photosensitive retinal cone cell and the electrochemical activity (i.e. the shape of neural impulbes) generated in that cone cell.

References and Notes

Unedited references as provided by the author.


6. Vivid strips of high contrast are also observed while the image is viewed still. Accommodation of the ocular lens and spatial frequency modulation of contrast sensitivity in early vision, also affecting transitory apparent contrast, are likely sources for stationary apparent contrast. This paper focuses exclusively on transitory apparent contrast during relative displacement between observer and image. The dynamic contrast effect referred to here is more salient than, for example, streaming motion in stationary pictures (see Levant, J. “Illusory Motion within Still Pictures: The L-Effect,” Leonardo 15, No. 3 (222–223, 1982). However, these apparently separate effects may share a common neural origin.


15. Van Tonder, G.J. and Ohtani, Y. “Effective velocity and transitory contrast loci” (in press).

16. Van Tonder and Ohtani [13,15].

17. Van Tonder and Ohtani [13].

18. Zanker, J.M., Doyle, M. and Walker, R. “Gaze stability of observers watching Op Art pictures” Perception 32, pp. 1057–1049 (2003). Note that Zanker et al. used mathematically produced line images resembling Fall, but without articulated low spatial frequency structure as shown in Fig. 5a. Omission of this stabilizing visual structure should affect subject eye movements.

19. Van Tonder and Ohtani [15].


21. An informal survey on a group of graduate students majoring in fine arts or design determined whether they rated Fall more visually interesting when viewed at high contrast, that is, when transitory contrast is vivid, or low contrast, where it practically disappears. The greater majority rated the high contrast image as more interesting, indicating that the transitory contrast is a necessary aspect of the visual appeal in this composition.


27. The slope of the logarithm of the Fourier Power Spectrum is often used as a measure of the strictness and dimensionality of fractal properties of pictures.


34. “Thinking about your study of Fall . . . there are some points I would like to comment on. The first
is to tell you how I made the curve in the first place, and the second is about the execution.

"I spent three years at my first art school almost entirely in the life room drawing. One of the most important things in figure drawing is the balance of weight. If one drops a mental plumb-line from the nape of the neck to the floor one can see more clearly the distribution of weight around the vertical. In drawing the curve for Fall I drew first the plumb-line and then the side-to-side movements of the curve as it descended to the ground. For me, there has always been a figurative reference in the painting, this being how we stand and how we move.

"In terms of the execution it has always been very important to me that the work is painted with a handheld brush and that while the aim is to do it as well as possible, as practising an objective skill and avoiding any autobiographical mark, it should not look mechanical." Riley, B. Personal communication (2006).

35. See van Tonder and Ohtani [15] and Zanker, J.M. “Looking at Op Art from a computational viewpoint” Spatial Vision 17(1), pp. 75–94 (2004). Interestingly, Zanker’s hypothetical model—of motion detectors in human vision—predicts that stimulus structure with highest effective velocity should be more salient, thus diametrically opposing the retinal cone model (lowest effective velocity) presented here. Since lowest effective velocity closely predicts my own observations, I am yet to be convinced otherwise.


Nanotechnology, Nanoscale Science and Art

Leonardo Special Section

Guest Editor: Tami I. Spector

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Color Plate B1 Contrast patterns seen for (a) vertical translation (up-and-down movement of the stimulus), (b) rotation around its centre, and (c) scaling (moving the stimulus further away and closer, in quick succession, while gazing at the centre of the image). The greenish-blue ribbons indicate regions seen in highest contrast. These images have been obtained with a computational model of primate retinal cone cells.
Color Plate B2 Spatial distribution of painted line width in *Fall*. Purple pixels indicate white lines exceeding the average width of white lines by at least 5%. Orange indicates similar results for black lines. Note that purple and orange regions hardly overlap. The canvas is divided into a central triangular area of thicker dark lines, flanked by regions of mixed line dominance. Line width was measured along the medial axis per line, quantified as the radius of the largest inscribed disc per location. Since the composition consists of horizontally displaced elements, line width values were processed along horizontal rows. Here, it constituted smoothing over 4 nearest neighbors, and normalization per horizontal line.