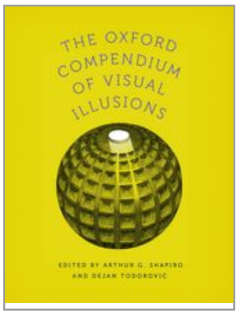

The Oxford Compendium of Visual Illusions
Arthur G. Shapiro and Dejan Todorovic

Print publication date: 2017
Print ISBN-13: 9780199794607
Published to Oxford Scholarship Online: June 2017
DOI: 10.1093/acprof:oso/9780199794607.001.0001

The Fraser-Wilcox Illusion and Its Extension

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DOI:10.1093/acprof:oso/9780199794607.003.0068

Abstract and Keywords

The Fraser-Wilcox illusion is one of the anomalous motion illusions observed in a stationary image, and its extension, including “rotating snakes,” which has been used extensively via the Internet, are reviewed in this chapter. Perceptual dimorphism featuring the Fraser-Wilcox illusion is explained by an interaction between two different illusions. Darkening disambiguation of the Fraser-Wilcox illusion, perceptual dimorphism, the optimized Fraser-Wilcox illusions, the effect of age on the illusion magnitude, as well as the role of color including color enhancement are demonstrated and discussed. The timing-difference model and the eye-movement model are also explored. Recent studies that relate to these concepts are also examined.

Keywords: illusion, Fraser-Wilcox illusion, motion, perceptual dimorphism, rotating snakes, color

Introduction

This chapter reviews the Fraser-Wilcox illusion, an anomalous motion illusion displayed as a stationary image, and its extension, for which I have produced a variety of illusion works (see Kitaoka, 2015). The Internet has made one of these (Fig. IV.68-1) popular with the public. This illusion is sometimes called the rotating snakes illusion (e.g., Billino, Hamburger, & Gegenfurtner, 2009; Kuriki, Ashida, Murakami, & Kitaoka, 2008), but I suggest that this illusion should be an “optimized version” of the Fraser-Wilcox illusion rather than a new illusion.

Anomalous Motion Illusions

A variety of visual illusions involving shape, color, lightness, depth, motion, faces, and so on have been discovered since the 19th century. In the history of the study of motion illusion, most stimuli, needless to say, have been moving **(p. 501)** objects, for example a fall in the waterfall illusion (motion aftereffect; Mather, Verstraten, & Anstis, 1998), moving rectangles in the footstep illusion (Anstis, 2000), or moving ellipses in the swimmers illusion (Shapiro, Knight, Palmor, & Mancusi, 2006). On the other hand, the study of anomalous motion illusions, which feature the use of stationary stimuli, started in the middle of the 20th century and has accelerated since the 1980s.

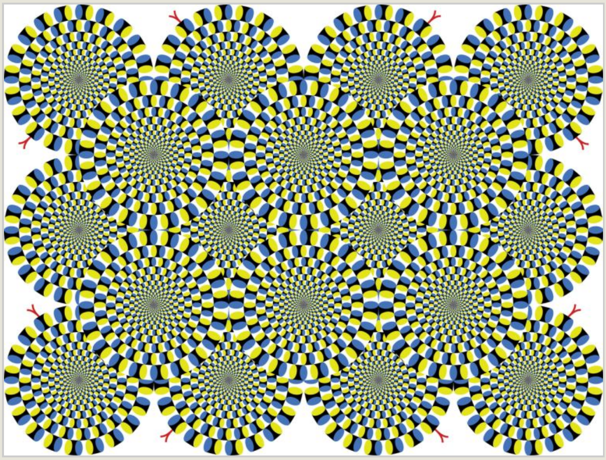


Figure IV.68-1. The rotating snakes illusion, which I produced in 2003 and have exhibited on the Internet. Each disk appears to rotate automatically in the constant direction (i.e., from black, blue, white, yellow, and back to black). (Figure by Akiyoshi Kitaoka.)

Three classes of anomalous motion illusions can be distinguished (Kitaoka & Ashida, 2007). The first class refers to *scintillating* phenomena, which are often observed in op-art, for example the MacKay (1957) ray pattern, the Enigma painting (Leviant, 1996), Bridget Riley's "Fall" (Zanker, Doyle, & Walker, 2003), and others. The second class is characterized by *sliding* phenomena, which are induced by the retinal slip of an image. This class consists of two subclasses. One is characterized by an illusory motion, the direction of which is different from or perpendicular to the retinal slip. This subclass includes the Ouchi-Spillmann illusion (Spillmann, 2013; Spillmann, Heitger, & Schuller, 1986), the Hine illusion (Hine, Cook, & Rogers, 1995), the Pinna illusion (Pinna & Brelstaff, 2000), and the drifting spines illusion (Kitaoka, 2010b), among others. The other is characterized by another illusory motion, the direction of which is the same as or opposed to the direction of the retinal slip. This subclass includes the fluttering-heart illusion (Helmholtz, 1867/1962), the floating-motion illusion (Pinna & Spillmann, 2002), the visual-delay-dependent motion illusion (Kitaoka & Ashida, 2007), and others. The third class refers to *automatically moving* phenomena, in which illusory motion appears in a constant direction guided by patterns. This class includes the Fraser-Wilcox illusion (Fraser & Wilcox, 1979) and its extension reviewed in this chapter, the central drift illusion (Fermüller, Ji,

& Kitaoka, 2010; Kitaoka & Ashida, 2004), the drifting arrows illusion (Kitaoka, 2010a), and others.

The Fraser-Wilcox Illusion

Fraser and Wilcox (1979) were the first to propose the third class of anomalous motion illusion. They called it the “escalator illusion” because of the cochlea-like appearance of the image (Fig. IV.68-2). This pattern is made up of pie slices filled with repeated luminance gradients and appears to rotate “automatically” when observers see the image. This image was painted by Alex Fraser (1923–2002), who was a geneticist known as “one of the first to conceive and execute computer simulations of genetic systems, and [his] efforts in the 1950s and 1960s had a profound impact on computational models of evolutionary systems” (Fogel, 2002, p. 429). He was a painter too. Some of his paintings can be seen at http://doctoralexfraser.blogspot.jp/. According to this site, the escalator painting was on canvas and was the one he used for testing the motion effect.

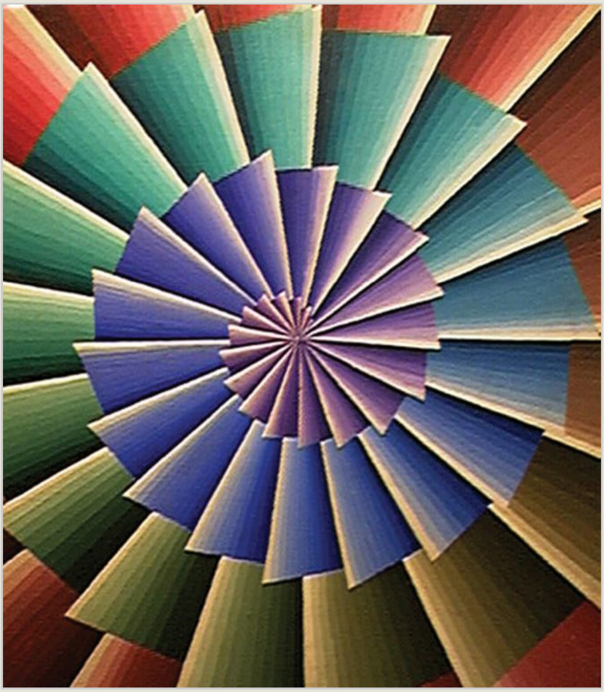


Figure IV.68-2. Alex Fraser’s original painting (Fraser, 2006). According to Fraser and Wilcox (1979), it is expected that some observers see the disk rotate clockwise while others see the opposite. (Reproduced with permission of Alan Fraser.)

Fraser and Wilcox (1979) reported a perceptual dimorphism—that is, some observers saw motion in the direction of light shading while others reported motion in the direction of dark shading. A parent–child survey suggested a genetic origin for the observer’s directional perception. However, several studies that examined the Fraser-Wilcox illusion failed to reproduce perceptual dimorphism and concluded that only the illusory motion from dark to light shading exists (Cloete, Wallis, Walterso, & Broerseo, 2004; Faubert & Herbert, 1999; Naor-Raz & Sekuler, 2000). Strictly speaking, Faubert and Herbert (1999) reported one exceptional observer from more than 200 observers; this person saw the illusory motion from light to dark shading. Naor-Raz and

Sekuler (2000) stated that they had confirmed perceptual dimorphism, yet they only reported the illusion from dark to light shading.

The Fraser-Wilcox illusion is stronger in the peripheral vision than in the central vision (Faubert & Herbert, 1999; Fraser & Wilcox 1979; Naor-Raz & Sekuler, 2000). Faubert and Herbert claimed that this illusion is triggered by eye movement or a blink and called it the peripheral drift illusion. They assumed that this illusory motion is based on the difference in visual latency between light and dark parts in luminance gradients. Since light parts would give a shorter latency than dark ones, light–dark borders should have a larger timing difference than luminance gradients, thus producing a stronger motion signal across the border. Naor-Raz and Sekuler revealed that the illusion magnitude is a positive, nearly linear function of contrast. Moreover, testing an aphake, they ruled out fluctuations of accommodation as a possible source, as did Cloete et al. (2004).

Disambiguation of the Fraser-Wilcox Illusion by Darkening or Lowering Contrast

I recently found that the illusory rotation from dark to light shading is made clear by darkening the whole image (Kitaoka, 2012). Compare the basic image (Fig. IV.68-3a) with its darkened one (Fig. IV.68-3b). The illusion from light to dark shading is hidden or suppressed. This effect is strong when the background is of an intermediate luminance (gray) of the shading. I suggest that the luminance arrangement of three areas meeting at a T-junction, not luminance gradients, is the critical component. When the two areas flanking the stem are light and dark, respectively, and the root side is of an intermediate luminance, illusory motion is directed from light to dark. This idea is embodied in Fig. IV. 68-3c, which does not comprise luminance gradients but blocks of three luminance areas.

Darkening an image is inevitably accompanied by lowered contrast. It seems that lowering contrast alone can serve to emphasize the illusory rotation from dark to light shading (Fig. IV.68-3d). This observation disagrees with Naor-Raz and Sekuler's (2000) finding that the illusion magnitude is a positive, nearly linear function of stimulus contrast. This contradiction could be solved by assuming the illusions shown in Figures IV.68-3b, IV.68-3d, and IV.68-3e are different from that of Naor-Raz and Sekuler (2000), who used a light background.

Naor-Raz and Sekuler (2000) used a color image for a screening test prior to the formal test, in which the disk was dark and surrounded by a gray area (Fig. IV.68-3e). This condition agrees with the condition for the darkening disambiguation discussed here. Moreover, Cloete et al. (2004) adopted an image surrounded by a gray background, and the test stimulus was relatively dark (mean: 26 cd/m^2) **(p.502)** according to the authors' unpublished handout. This condition also accords with the darkening disambiguation.

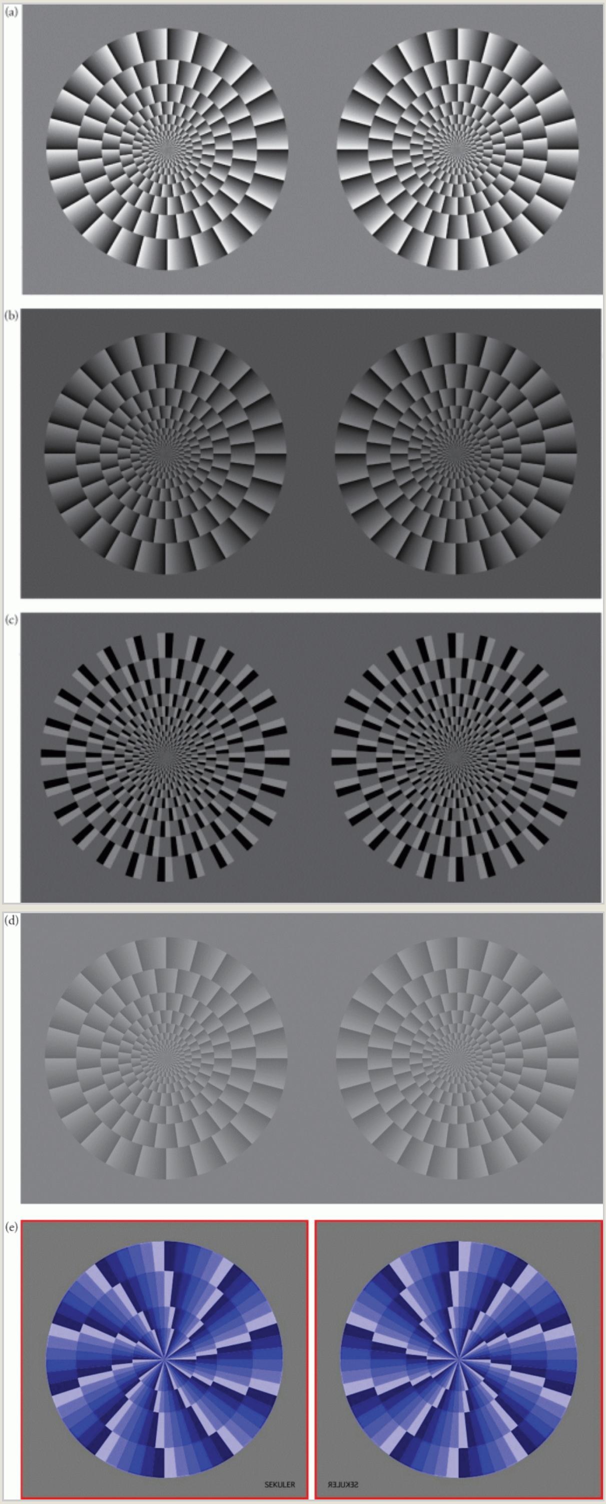


Figure IV.68-3. Disambiguation by darkening or lowering contrast. (a) A simplified, basic image for the Fraser-Wilcox illusion. The direction of perceived rotation appears to be unstable. In the following panels (b) through (e), the left disk appears to rotate clockwise while the right one counterclockwise. (b) Darkening disambiguation of the Fraser-Wilcox illusion by darkening the image (a). (c) A stepwise version of (b), which suggests that luminance gradients are not indispensable for this illusion. (d) Lowering contrast disambiguation of the Fraser-Wilcox illusion through modification of the image (a). (e) Naor-Raz and Sekuler's (2000) screening test image, reproduced with permission of Robert Sekuler. The left half is the original and the right one is its mirror image. Their image could be included in this category. (Figure by Akiyoshi Kitaoka except (e).)

Perceptual Dimorphism

The Fraser-Wilcox illusion appears differently depending on whether the background luminance is light or dark. The illusory rotation from dark to light shading is frequently observed when the luminance of the background is the same or higher than the highest luminance in the gradients (Figure IV.68-4a), whereas the illusory rotation from light to dark shading is predominant when the luminance of the background is the same or lower than the lowest luminance in the gradients (Fig. IV.68-4b). My suggestion is that these two opposing illusions might have contributed to perceptual dimorphism or have cancelled each other out.

Thus the Fraser-Wilcox illusion includes at least three different illusions, two being illusions from dark to light shading (Figures IV.68-3b and IV.68-4a) and the other an illusion from light to dark shading (Figure IV.68-4b). This suggestion would also be supported by the finding of "substantial individual variation in the perception of Fraser-Wilcox stimuli, but little variation in the snakes illusion" (Becker & Mollon, 2007, p. 62).

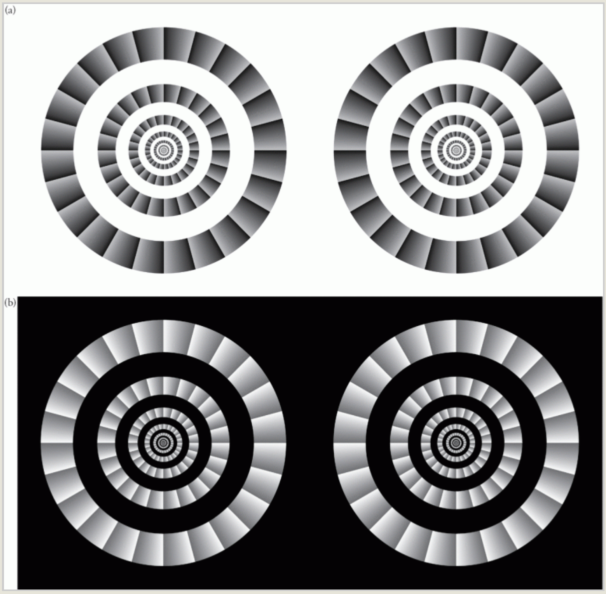


Figure IV.68-4. Background luminance dependency. In each panel, the left disk appears to rotate clockwise while the right one counterclockwise. (a) When the luminance of the background is the same or higher than the highest luminance in the gradients, the direction of illusory motion is from dark to light shading. (b)

In addition, perceptual dimorphism is observed in particular color combinations. Dark to light shading from purple to red via red-purple surrounded by a red-purple background gives an illusory motion in the direction from dark to light shading (Figure IV.68-5a). On the other hand, light to dark shading from light red-purple (magenta) to red-purple via red surrounded by a red background renders an illusory motion in the direction from light to dark shading (Figure IV.68-5b). Moreover, gradients may not be indispensable for these illusions (see Figs. IV.68-5c and IV.68-5d) like darkening disambiguation. This issue is discussed again later in the chapter.

When the luminance of the background is the same or lower than the lowest luminance in the gradients, the direction of illusory motion is from light to dark shading. (Figure by Akiyoshi Kitaoka.)

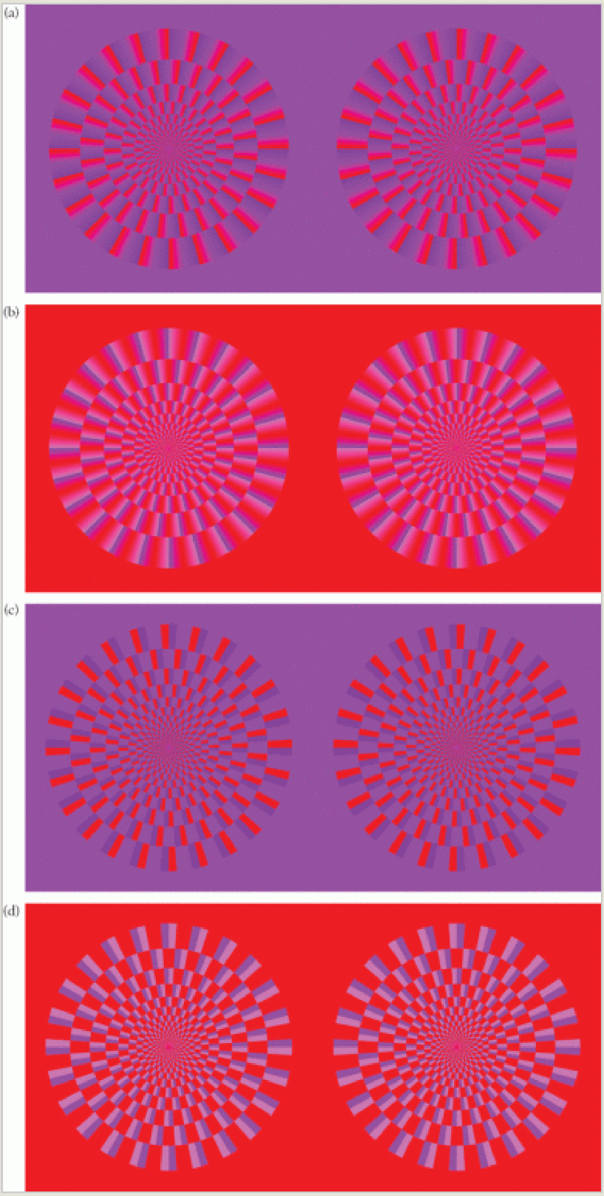


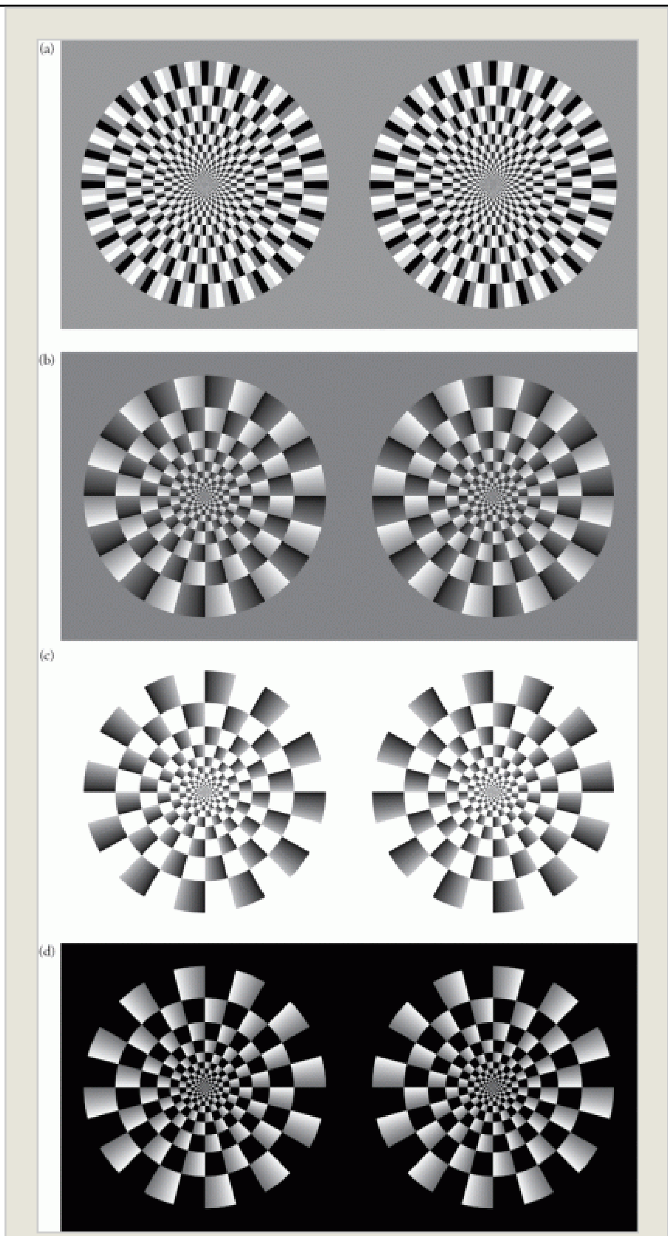
Figure IV.68-5. Color-dependent perceptual dimorphism. In each panel, the left disk appears to rotate clockwise while the right one counterclockwise. (a)

A particular color combination promotes the illusion from dark (purple) to light (red) shading. (b) Another particular color combination promotes the illusion from light (light red-purple or magenta) to dark (purple) shading. (c) and (d) Simplified versions of (a) and (b), respectively, which suggest that gradients are not indispensable for these illusions. (Figure by Akiyoshi Kitaoka.)

The Optimized Fraser-Wilcox Illusion

Kitaoka and Ashida (2003) proposed a new painting rule to draw images that can demonstrate a much stronger illusion (Figure IV.68-6a) than previous Fraser-Wilcox patterns. The proposed rule was a four-stroke luminance combination, and the order is black, dark gray, white, light gray, and back to black. When this combination is repeated, a strong illusion can be observed in this direction. The rotating snakes (Figure IV.68-1) illusion simply follows this rule.

Figure IV.68-6b shows its shading variation, which Kitaoka (2006b, 2007) called the “optimized Fraser-Wilcox illusion, Type I.” The illusion shown in this figure is a composite between the illusion from dark to light shading with a lighter surround (Figure IV.68-6c) and the illusion from light to dark shading with a darker surround (Fig. IV.68-6d). These images correspond to Figures IV.68-4a and IV.68-4b, respectively. The limited cases are listed in the top row of **(p. 503)** Figure IV.68-7. The luminance of the surround relative to the luminance gradients is critical.



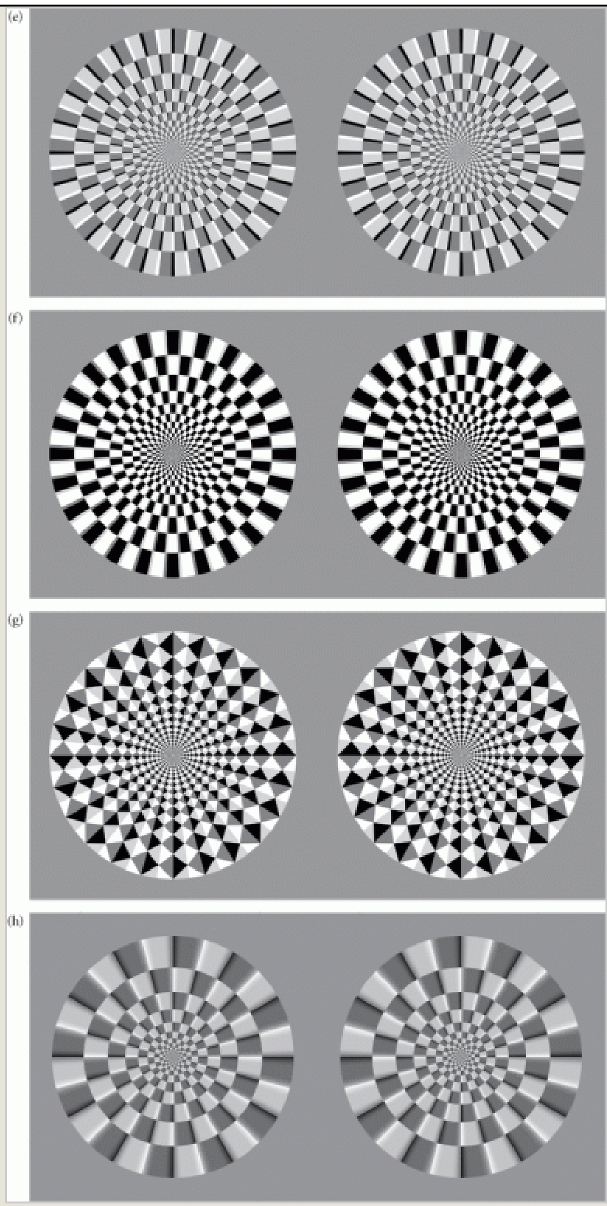


Figure IV.68-6. The "optimized" Fraser-Wilcox illusion. In each panel, the left disk appears to rotate clockwise while the right one counterclockwise. (a) Kitaoka and Ashida's (2003) original version. The illusory motion is directed from black, dark gray, white, light gray, and back to black. (b) Type I, the shading version. The illusory motion is directed from black to gray shading and from white to gray shading. (c) The illusion from dark to light shading within Type I. (d) The illusion from light to dark shading within Type I. (e) Type IIa, in which the basic pattern consists of three areas of

Figure IV.68-6e shows a three-luminance-step illusion, which Kitaoka (2007) called “Type IIa.” The basic image consists of three areas of different luminances, with one thinner area flanked by thicker areas (see the Type IIa row in Fig. IV.68-7). The thinner area should be the darkest or the lightest among the three areas. This type also comprises two opposing illusions. One is the illusory motion directed from light gray to dark gray via black; the other **(p.504)** is the direction from dark gray to light gray via white. In this connection, Figure IV.68-6f shows another three-luminance-step illusion, which Kitaoka (2007) called “Type IIb,” in which the thinner area is of an intermediate luminance between the flankers. When the thinner area is dark gray, the illusory motion is in the direction from black to white via dark-gray; when the thinner area is light gray, the illusory motion is in the direction from white to black via light gray (see the Type IIb row in Fig. IV.68-7). In addition, there is a close, pictorial resemblance in the basic images between Type IIa and “reversed phi movement” (Anstis, 1970; Anstis & Rogers, 1975) and between Type IIb and “phi movement” (Gregory & Heard, 1983; for a review see Kitaoka, 2006a).

different luminance. The illusory motion is in the direction from light gray to dark gray via black or in the direction from dark gray to light gray via white. (f) Type IIb, in which the basic pattern consists of three areas of different luminance. The illusory motion is in the direction from black to white via dark gray or in the direction from white to black via light gray. (g) Type III, in which the basic pattern consists of two areas of different luminance. The illusory motion is in the direction from black to dark gray or in the direction from white to light gray. (h) Type IV, which is observed outdoors at lighted or shaded bulges or concaves. The illusory motion is in the direction from a darker edge to the adjacent darker area or in the direction from a lighter edge to the adjacent lighter area. See Figure IV.68-7. (Figure by Akiyoshi Kitaoka.)

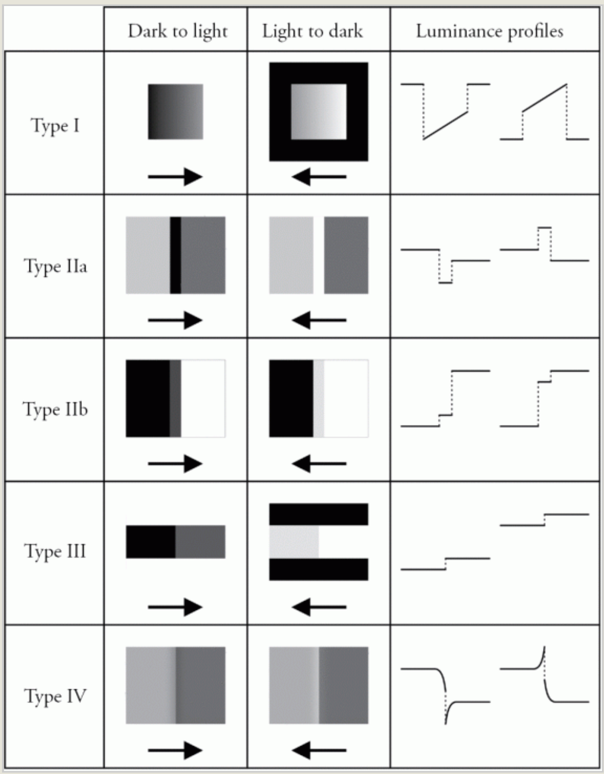


Figure IV.68-7. A classification of the "optimized Fraser-Wilcox illusion" family. Here are five types, each with two opposing illusions ("dark to light" and "light to dark"). The basic images of each type and their luminance profiles are shown. Arrows indicate the direction of illusory motion. (Figure by Akiyoshi Kitaoka.)

Two luminance steps in a row also produce an illusion. Kitaoka (2007) called it "Type III" (Fig. IV.68-6g). This type comprises two illusions. One is the illusory motion directed from black to dark gray when the image is surrounded by a lighter area; the other is the direction from white to light gray when the image is surrounded by a darker area. These limited cases are shown in the Type III row of Figure IV.68-7.

Figure IV.68-6h shows a variation that makes a convex or concave impression because edges are shaded or highlighted so as to generate shape-from-shading phenomena (Horn, 1975; Ramachandran, 1988). Kitaoka (2008a, 2008b) called it "Type IV." This variation comprises two illusions. One is the illusory motion directed from a darker edge to the adjacent dark area; the other is the direction from a lighter edge to the adjacent light area (see the Type IV row of Fig. IV. 68-7).

In sum, I propose 10 basic illusions (five types by two directions) as listed in Figure IV.68-7. Since this classification remains at the pictorial level, it is necessary to reveal the underlying mechanisms in the next step.

Enhancement by Color

Although the optimized Fraser-Wilcox illusion basically depends on the spatial arrangement of luminance, color enhances the illusion. There are two types of color enhancement. For the first type, any color combination will work. According to my experience, red or blue most strongly enhances the illusory motion from dark to light, whereas yellow or green strongly enhances the illusory motion from light to dark. Figure IV.68-8a shows an example that corresponds to a colored image of Type I, in which the dark to light shading is replaced with a black to magenta shading (magenta is a composite of red and blue) while the light to dark shading is replaced with a yellow to yellowish-green shading. This method of color enhancement has been implemented with success in all types of the optimized Fraser-Wilcox illusion (Kitaoka, 2007, 2008a, 2008b, 2010a). **(p.505)**

For the second type, a combination of red and blue plays a part. Shaul Baskin, chief of Wezit Research Group (http://www.visnsoft.com/), developed a novel, still stronger color enhancement before 2005. He drew my attention to his website by e-mail in August 2005, before which I was not aware of this type of color enhancement. According to my observations, the best combination is the arrangement from purple, red-purple, magenta (light red-purple), red, and back to purple. Purple should be darkest and magenta should be lightest. Figure IV.68-8b shows an example that corresponds to a colored image of Type I. The base color is red and the modulating color is blue, though some of Baskin's works include orange instead of magenta. The color illusions shown in Figure IV.68-5 may also be included in this type.

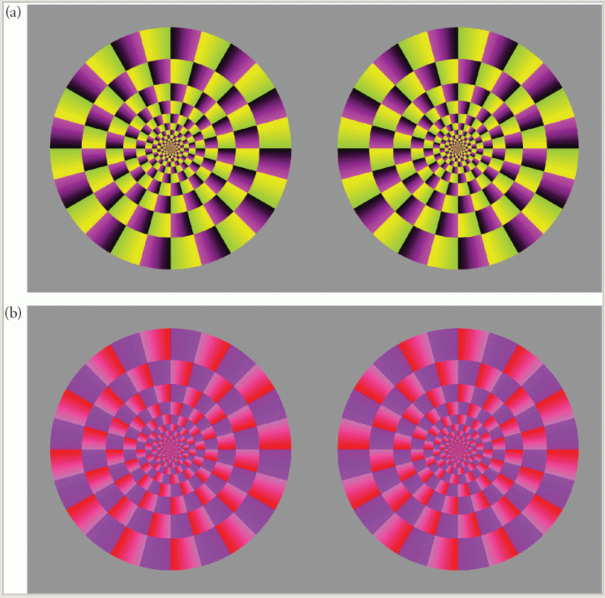


Figure IV.68-8. Color enhancement. In each panel, the left disk appears to rotate clockwise while the right one counterclockwise. (a) Red or blue (purple when mixed) enhance the illusion from dark to light shading while yellow or green increase the illusion from light to dark shading. (b) A particular combination of red and purple gives a strong illusion. (Figure by Akiyoshi Kitaoka.)

The Effect of Age

Fluctuation of accommodation is unlikely to contribute much to the Fraser-Wilcox illusion. Naor-Raz and Sekuler (2000) examined an 82-year-old bilateral post-op aphake. This person reported the illusion, and his ratings were similar to those of younger participants.

In connection with this observation I collected data from more than 1,000 people to examine whether age is related to the rotating snakes illusion (Fig. IV.68-1). I distributed a high-resolution A4-size print of the picture to participants who came to my lectures or events in schools or museums and asked them to rate the strength of illusion based on the following scale: "I saw no apparent motion" (zero), "I slightly saw apparent motion" (1), "I saw apparent motion" (2), and "I saw strong apparent motion" (3). In total, 1,863 people participated, and their ages were between 2 and 92 years. The results are shown in Table IV.68-1. As a whole, a weak but significant negative correlation between age and illusion was observed ($r = .33$, $df = 1861$, $p < .01$), a result consistent with a previous study (Billino et al., 2009). The result does not support the accommodation hypothesis, because the majority of elder participants, even those in their **(p. 506)** **(p.507)** **(p.508)** **(p.509)** 80s, saw the illusion. Moreover, about 1% of young participants did not see the illusion, while they did not report any accommodative problems or any other disorder in vision. In addition, it was suggested that infants ages 6 to 8 months see this illusion (Kanazawa, Kitaoka, & Yamaguchi, 2013).

Table IV.68-1. The effect of age on the "Rotating snakes" illusion

Age	n	Score			
		0	1	2	3
0–9	169	0%	6%	17%	78%
10–19	710	1%	6%	19%	74%
20–29	219	1%	6%	27%	65%
30–39	219	1%	7%	21%	70%
40–49	221	2%	9%	29%	60%
50–59	138	8%	19%	30%	43%
60–69	98	5%	28%	38%	30%
70–79	61	15%	25%	33%	28%
80–92	28	21%	7%	39%	32%
Total	1863	3%	9%	24%	64%

Rating scores 0, 1, 2, 3 mean that observers reported no illusion, a slight illusion, an illusion, a strong illusion, respectively. Percentages indicate proportions in each age.

The factor of race or culture might play some part in perception of the rotating snakes illusion. Billino et al. (2009; in Germany) examined 38 senior adults (65 to 82 years old), 23.7% of whom saw the illusion. On the other hand, my study (Japan) showed that 86.2% of 123 senior adults (65 to 82 years old) saw this illusion. The majority of the younger observers saw this illusion in both studies.

The Timing-Difference Model and the Eye-Movement Model

The rotating snakes illusion is assumed to depend on timing differences between neural responses to different parts of the figure. Conway et al. (2005) explained this illusion in terms of contrast-dependent response timing differences and related it to four-stroke apparent motion (Anstis & Rogers, 1986; Mather & Murdoch 1999). Backus and Oruç (2005) also explained this illusion (referring to "repeated asymmetry patterns") in terms of response timing differences, while they also took into account the process of adaptation to luminance as well as contrast. According to these timing-difference models, illusory motion arises from peak shifts of perceived patterns.

On the other hand, Murakami et al. (2006) stressed the role of fixational eye movements in this illusion and a failure **(p.510)** to compensate for the micromovements and explained it with the gradient model, which assumes a negatively biased temporal kernel. Relatedly, Fermüller et al. (2010) proposed the energy filter model assuming spatial symmetry and temporal asymmetry. According to these "eye movement" models, there is asymmetry in strength of motion signals depending on the direction of a moving pattern on the retina, and illusory motion arises from a difference of motion signals provided constantly by miniature eye movements. The involvement of fixational eye movement was supported by Kuriki et al. (2008) and Beer, Heckel, and Greenlee (2008).

Positive afterimages of the rotating snakes, given to dark-adapted eyes by a flash, did not generate the rotating snakes illusion (Murakami et al., 2006). This finding supports the eye-movement model. But the timing-difference model could also explain this finding by assuming that not a single flash but more frequent refreshments are necessary to maintain the illusion.

Using functional magnetic resonance imaging (fMRI) technology applied to the study of human brains, Kuriki et al. (2008) examined neural responses to the rotating snakes image (compared with responses to the control image) and revealed that neural activity of the motion-sensitive area hMT+ is correlated with the illusion. Moreover, this correlation was observed in two conditions that allowed eye movements but not in the condition that suppressed them. This finding supports the eye-movement model. Furthermore, using the fMRI adaptation technique, Ashida, Kuriki, Murakami, Hisakata, and Kitaoka (2012) revealed the activity of the cortical network for motion processing from V1 through hMT+.

Recent Studies

Using an optimized Fraser-Wilcox illusion array, Beer et al. (2008) observed the interaction of arrays placed in the central and peripheral fields. They revealed that illusory motion was not perceived in the central field and occurred only in the peripheral field. The illusion was strongest when the array of the latter was opposed to that of the former (the “incongruent” condition). Moreover, given the central field, which has the array potentially giving the illusion, illusion in the “opposite” direction was induced to the peripheral field even if it did not have the array giving illusion. Furthermore, this induction was absent when the central field was physically moving.

In connection, Tomimatsu, Ito, Seno, and Sunaga (2010) showed that the rotating snakes illusion is weak when the image is physically moved and claimed that “the image should remain stationary (without being refreshed) for some time on the same retinal position (p. 721).” To support the timing-difference model in accordance with this observation, an additional assumption that “refreshment is suppressed during smooth pursuit” might be necessary. On the other hand, to support the eye-movement model in accordance with this observation, an additional assumption (e.g., “miniature eye movements are suppressed during smooth pursuit”) would be necessary.

Hisakata and Murakami (2008) confirmed the anecdote that the rotating snakes illusion is better perceived in the visual periphery and is positively correlated with retinal luminance and suggested the involvement of a transient processing system by examining the human temporal impulse response. Cantor, Tahir, and Schor (2010) demonstrated that the rotating snakes illusion decreased when observers viewed the image through a pinhole or when they defocused it. They explained this finding by taking into account the modulation transfer function. Idesawa (2010) explained the optimized Fraser-Wilcox illusion Type IIa “by considering the isotropic spatial filtering process with time varying factor and visual reset (p. 557).” Tomimatsu, Ito, Sunaga, and Remijn (2011) showed evidence for the involvement of adaptation process both in the Fraser-Wilcox illusion and the optimized illusion.

In sum, many phenomena related to the Fraser-Wilcox illusion and its extension have been revealed, but their mechanisms are yet to be clearly understood.

Acknowledgments

This study was supported by JSPS Grant-in-Aids for Scientific Research (A18203036 and A22243044) and a Ritsumeikan University R-GIRO program awarded to the author. Special gratitude is extended to Akemi Yamamoto, Nobuko Takamatsu, and Chiba Museum of Science and Industry for their help in collecting data for the study of age and illusion. I also thank Hiroshi Ashida and Arthur Shapiro for their comments.

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