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# Color-dependent motion illusions in stationary images and their phenomenal dimorphism

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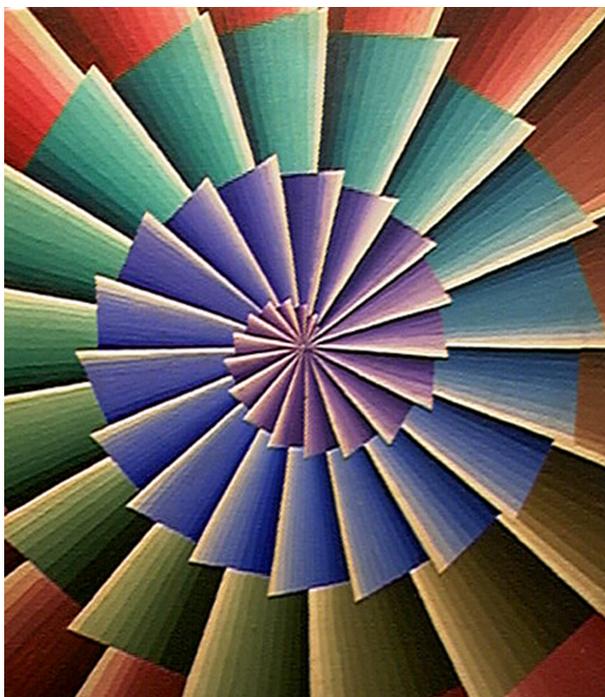
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**Abstract.** The color-dependent motion illusion in stationary images—a special type of the Fraser–Wilcox illusion—is introduced and discussed. The direction of illusory motion changes depending on whether the image is of high or low luminance and whether the room is bright or dark. This dimorphism of illusion was confirmed by surveys. It is suggested that two different spatial arrangements of color can produce the motion illusion. One is a spatial arrangement where long- and short-wavelength color regions sandwich a darker strip; the other is where the same color regions sandwich a brighter strip.

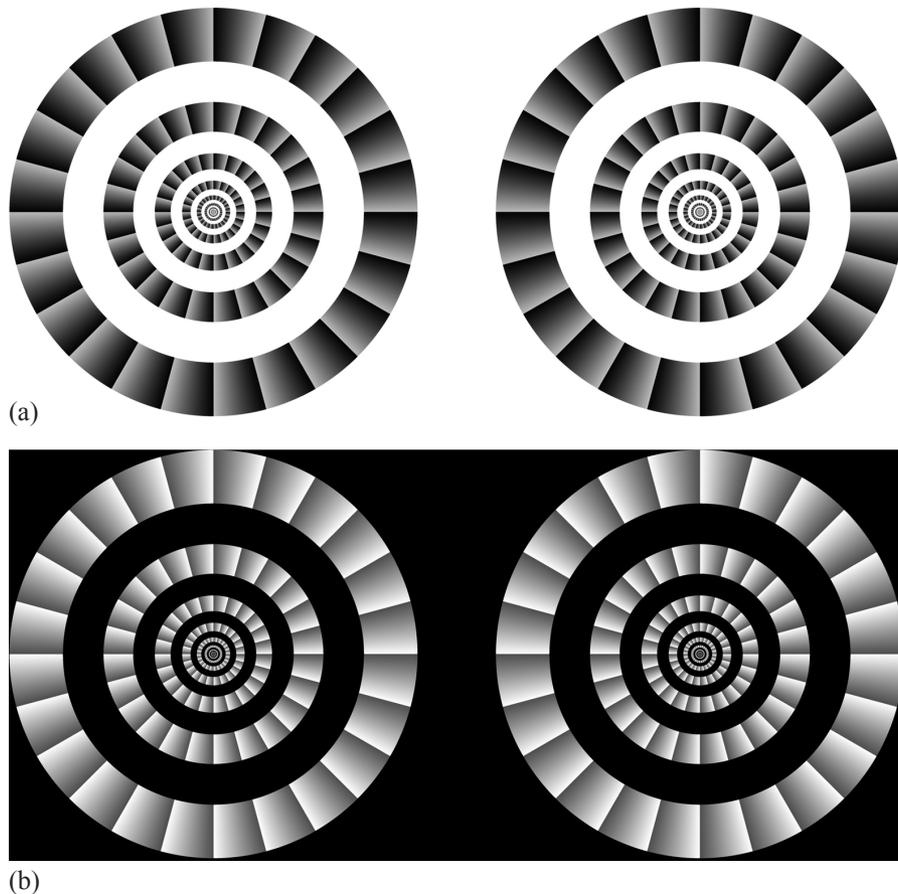
**Keywords:** color, motion, illusion, Fraser–Wilcox illusion, dimorphism

## 1 Introduction: Fraser–Wilcox illusion

Fraser and Wilcox (1979) described a motion illusion in a stationary image in which a pattern appears to move along repeated blocks of sawtooth luminance profile (figure 1). They reported that the direction of illusory motion was variable. Some observers saw illusory motion from dark to light along the luminance gradient, while others reported the reverse. This dimorphism was not confirmed for the subsequent two decades and was abandoned by some researchers (Faubert & Herbert, 1999; Naor-Raz & Sekuler, 2000), who investigated only the illusory motion from dark to light along a luminance gradient (figure 2a). However, the illusory motion from light to dark was later revisited (Kitaoka, 2007, 2008, 2010, 2012; Kitaoka & Newton Press, 2007) (figure 2b).



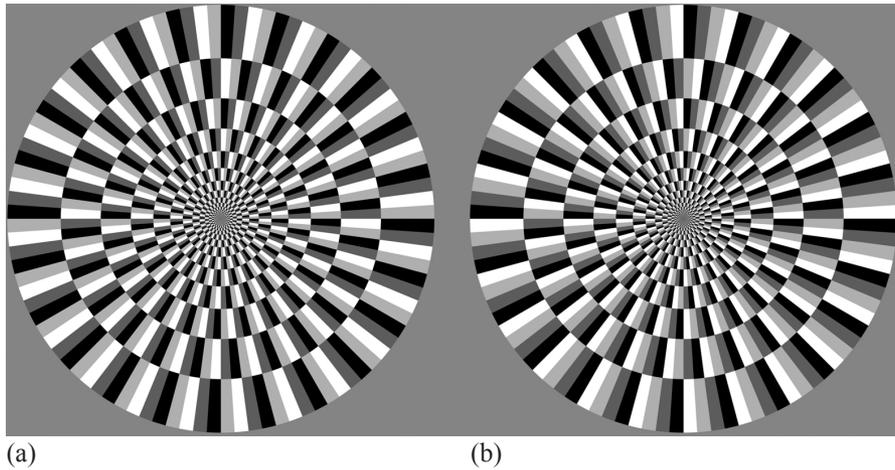
**Figure 1.** [In color online, see <http://dx.doi.org/10.1068/p7706>] Fraser's (2006) original painting. According to Fraser and Wilcox (1979), some observers saw the disk rotate clockwise while others saw it rotate counterclockwise. Courtesy of Alan Fraser.



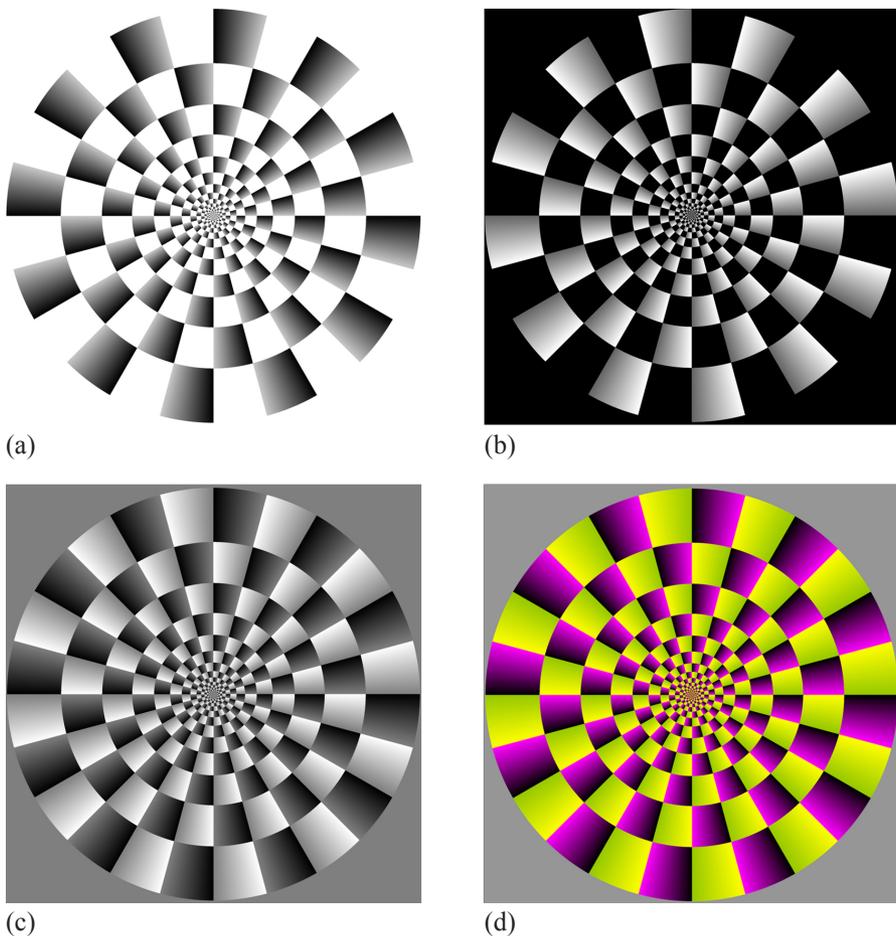
**Figure 2.** (a) A demonstration of the illusory motion from dark to light along a luminance gradient. The left rings appear to rotate clockwise while the right rings rotate counterclockwise. This illusion is strong when the background is brighter than the gradients. (b) A demonstration of the illusory motion from light to dark along a luminance gradient. The left rings appear to rotate counterclockwise while the right rings rotate clockwise. This illusion is strong when the background is darker than the gradients. Both illusions are strong in peripheral vision.

Kitaoka and Ashida (2003) proposed a way to enhance this illusion by turning over half of each gradient so as to make an arrangement of ‘black, dark gray, white, light gray’ (figure 3a) instead of ‘black, dark gray, light gray, white’ (figure 3b). I (Kitaoka, 2007, 2008) suggested that this enhanced illusion consists of two separate illusory motions, one being an illusory motion along the gradient from dark to medium luminance (from black to dark gray) (figure 4a) and the other being an illusory motion along the gradient from light to medium luminance (from white to light gray) (figure 4b). Both illusory motions cooperate to make a stronger illusion (figure 4c). Empirically, color might enhance the illusion (figure 4d), though luminance is primary and color would be secondary, if at all.

On the basis of these observations, I (Kitaoka, 2003) created a work entitled *Rotating Snakes* and exhibited it on a website (<http://www.ritsumei.ac.jp/~akitaoka/index-e.html>) (figure 5a), which led to a variety of studies (*psychophysics*: Beer, Heckel, & Greenlee, 2008; Hisakata & Murakami, 2008; Tomimatsu, Ito, Seno, & Sunaga, 2010; Tomimatsu, Ito, Sunaga, & Remijn, 2011; *neuroscience*: Ashida, Kuriki, Murakami, Hisakata, & Kitaoka, 2012; Conway, Kitaoka, Yazdanbakhsh, Pack, & Livingstone, 2005; Kuriki, Ashida, Murakami, & Kitaoka, 2008; *eye movement*: Murakami, Kitaoka, & Ashida, 2006; Otero-Millan, Macknik, & Martinez-Conde, 2012; *model*: Backus & Oruç, 2005; Fermüller, Ji, & Kitaoka, 2010; Idesawa, 2010; *development*: Billino, Hamburger, & Gegenfurtner, 2009;



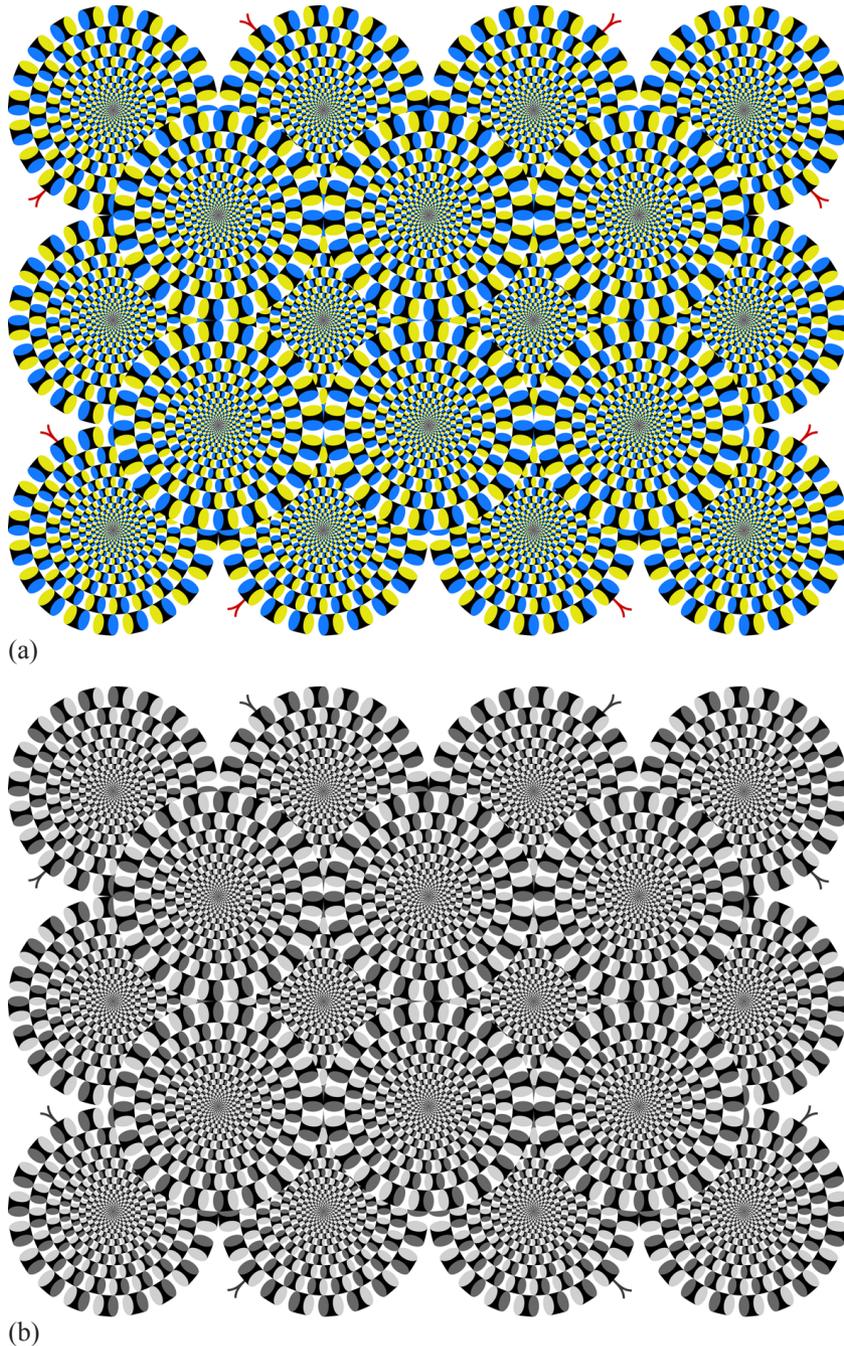
**Figure 3.** (a) Kitaoka–Ashida’s enhanced version of the Fraser–Wilcox illusion. The disk appears to rotate clockwise when viewed in peripheral vision. (b) The sawtooth–luminance–profile arrangement of the Fraser–Wilcox illusion. The disk may appear to rotate clockwise or counterclockwise in peripheral vision.



**Figure 4.** [In color online.] (a) Illusory motion from dark to light along a luminance gradient surrounded by a brighter area. This illusion corresponds to figure 2a. (b) Illusory motion from light to dark along a luminance gradient surrounded by a darker area. This illusion corresponds to figure 2b. (c) Stronger illusory motion is produced by (a) and (b) cooperatively. (d) Empirically, color may enhance the illusion. Each disk appears to rotate clockwise in peripheral vision.

Kanazawa, Kitaoka, & Yamaguchi, 2013; *experimental aesthetics*: Stevanov, Marković, & Kitaoka, 2012; Stevanov, Spehar, Ashida, & Kitaoka, 2012). Although *Rotating Snakes* was presented as a colored image, an achromatic version also works (figure 5b).

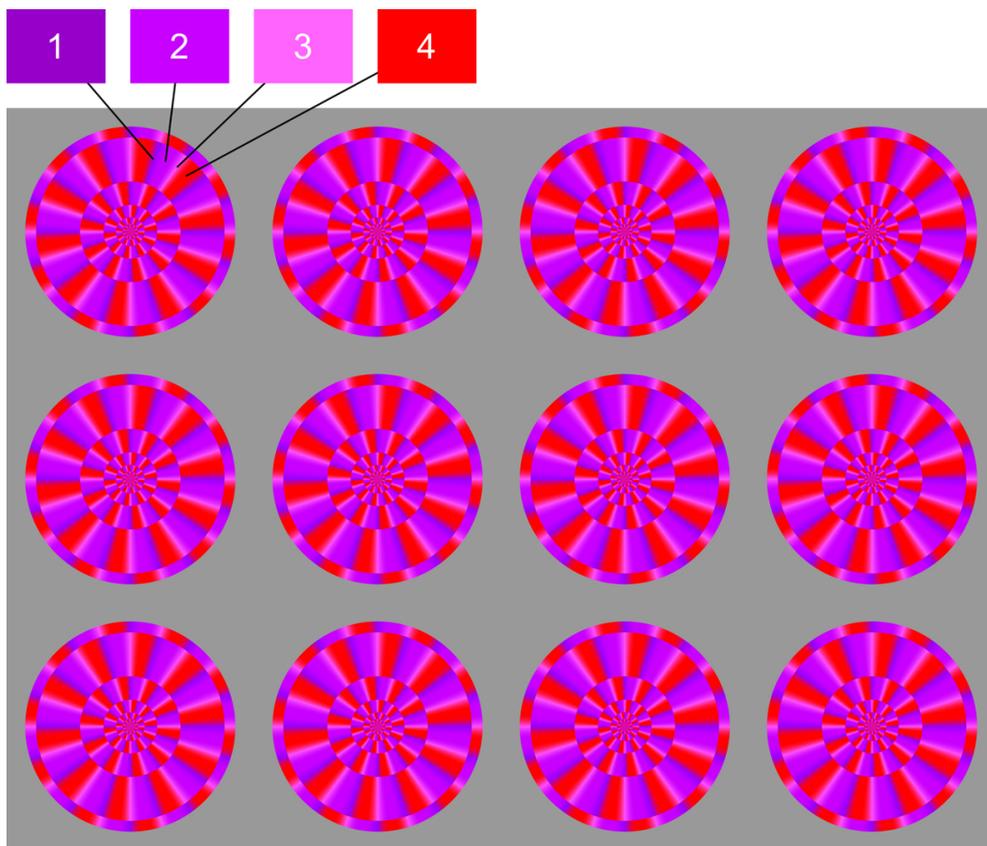
Over all the variations of the Fraser–Wilcox illusion, the illusion is stronger when the image is viewed in the visual periphery or when the image is of high luminance or of high luminance contrast (Hisakata & Murakami, 2008; Naor-Raz & Sekuler, 2000). Color was considered a factor that might enhance the illusion but not be essential.



**Figure 5.** [In color online.] (a) An illusion work *Rotating Snakes*. Each disk appears to rotate clockwise or counterclockwise. The direction of illusory motion is from black to blue, white, yellow, back to black. (b) Its gray-scale version. The direction of illusory motion is from black to dark gray, white, light gray, back to black.

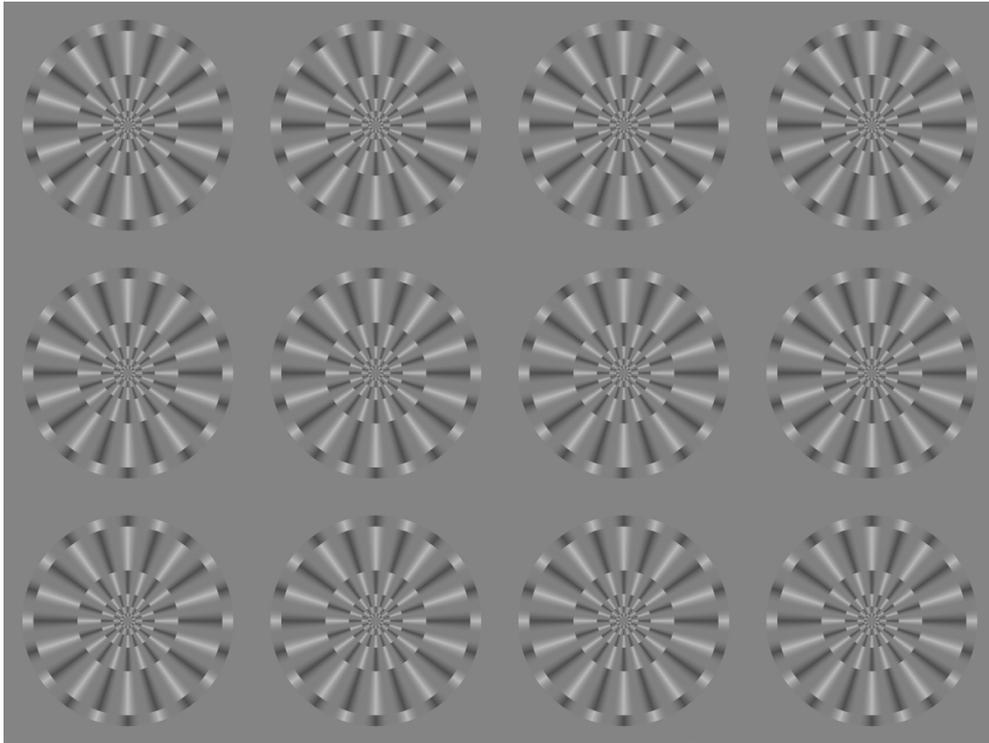
## 2 Color-dependent Fraser–Wilcox illusion

I (Kitaoka, 2013a, 2013b, 2013c, forthcoming; Kitaoka & Yanaka, 2013; Seno, Kitaoka, & Palmisano, 2013) proposed a strongly color-dependent variation of the Fraser–Wilcox illusion. Figure 6 shows an example, in which there are two different illusory motions depending on the condition of luminance or illumination. One illusory motion is observed on a bright PC display or in a printed image in a bright room, where each disk appears to rotate clockwise. Specifically, the direction of illusory motion is from purple to light purple, pink (or magenta), red, back to dark purple. The other illusory motion is observed on a dark PC display or in a printed image in a dark room, where each disk appears to rotate counterclockwise. This dramatic reversal has never been observed in the previous variations of the Fraser–Wilcox illusion (figures 1–4) or *Rotating Snakes* (figure 5).

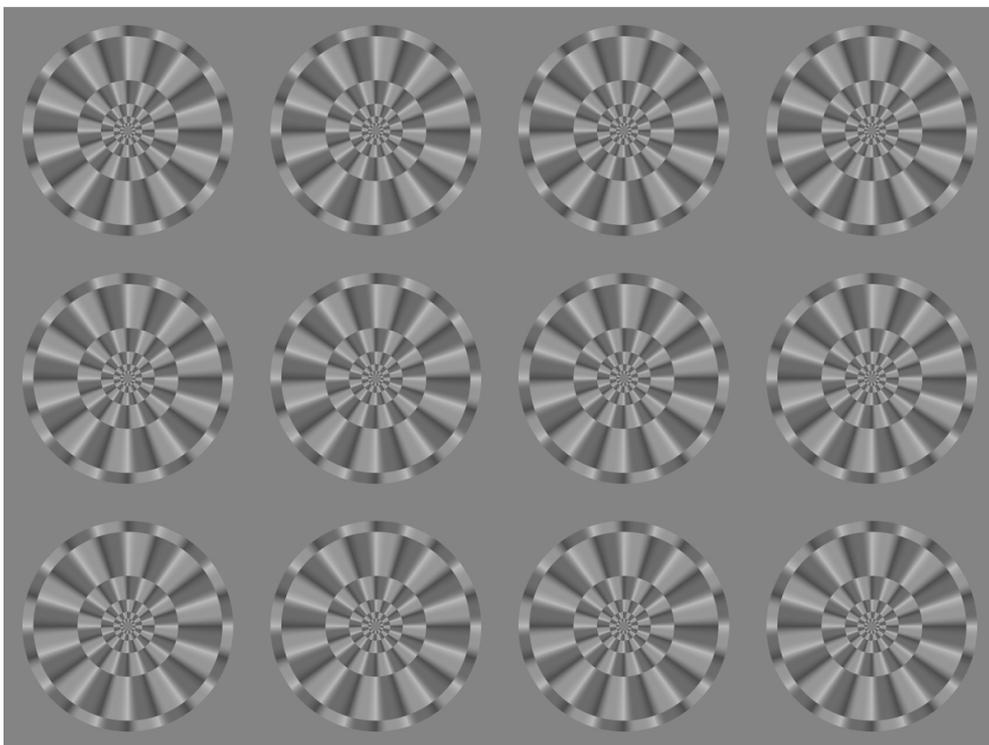


**Figure 6.** [In color online.] The color-dependent Fraser–Wilcox illusion. This color combination produces the strongest effect among all the color combinations ever examined. Each disk appears to rotate clockwise in a bright condition: that is, the direction of illusory motion is from purple (1) to light purple (2), pink (or magenta, 3), red (4), back to dark purple (1). On the other hand, each disk appears to rotate counterclockwise in a dark condition: that is, the direction of illusory motion is from purple (1) to red (4), pink (3), light purple (2), back to purple (1).

These illusions disappear or diminish when figure 6 is changed to a gray-scale image as shown in figure 7. This observation confirms the critical role of color in these effects. The illusions remain when purple and pink are changed to black and white, respectively (figure 8a). On the other hand, the illusions disappear when light purple and red are changed to grays (figure 8b). As a consequence, it is suggested that the optimal condition to make these illusions should be a spatial arrangement of long-wavelength and short-wavelength color regions that sandwich the darker or brighter strips (figure 9). In figure 6 the long-wavelength

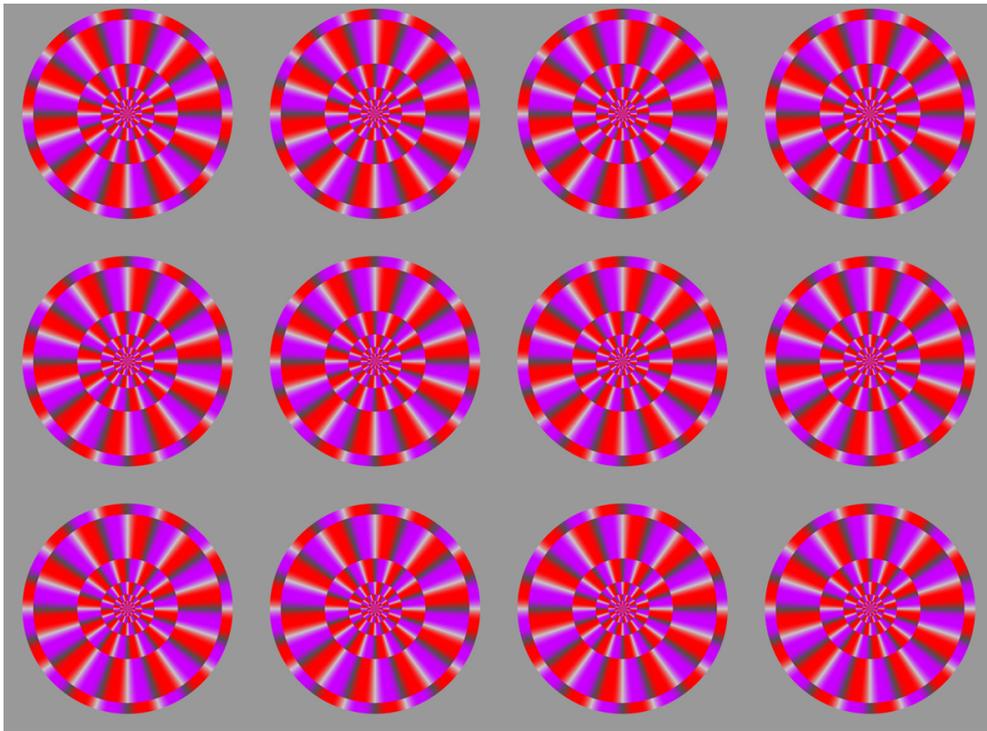


(a)

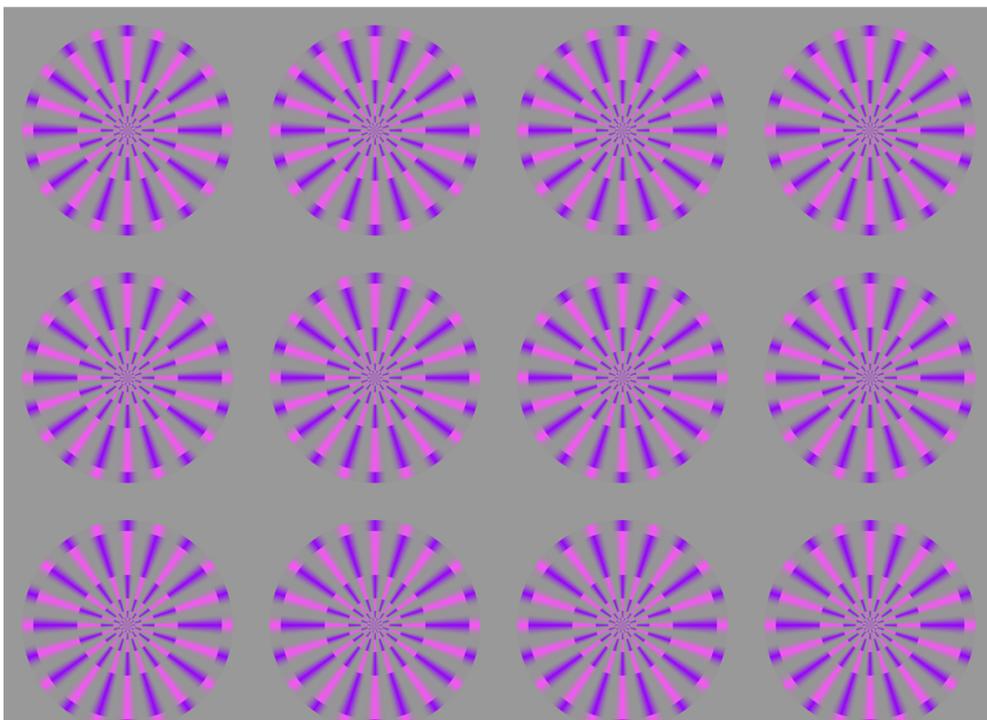


(b)

**Figure 7.** Gray-scale images corresponding to the color-dependent Fraser–Wilcox illusion image. If the light purple (2) and red (4) in figure 6 are the same luminance, (a) corresponds to figure 6 and gives little or no illusion. If they are slightly different in luminance, (b) represents a possible luminance profile of figure 6 and gives a much weaker or no illusion.

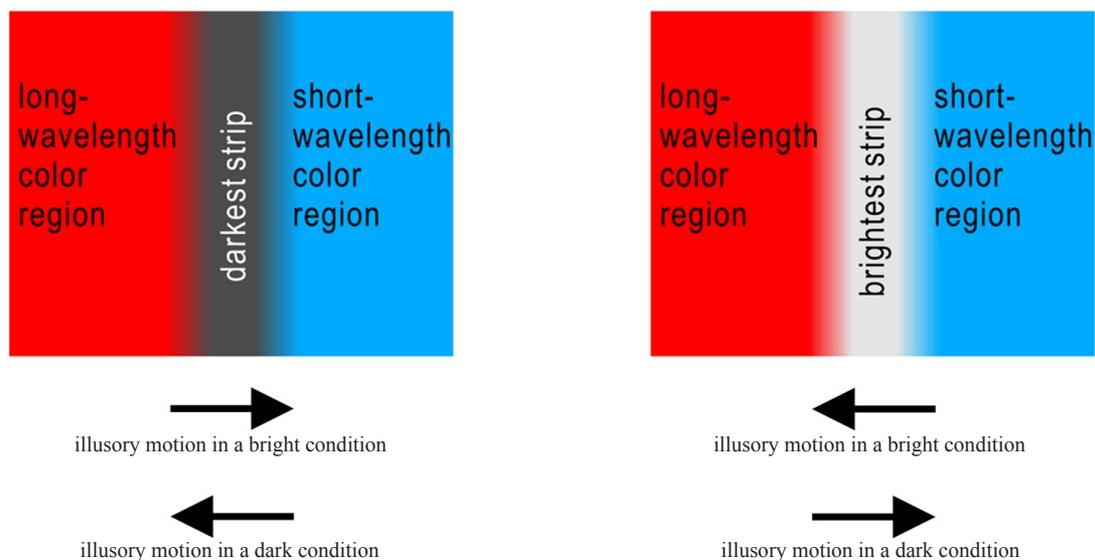


(a)



(b)

**Figure 8.** [In color online.] (a) The color-dependent Fraser–Wilcox illusion remains when purple (1) and pink (3) in figure 6 are changed to achromatic colors of similar lightness, respectively. (b) The illusion disappears or diminishes when light purple (2) and red (4) in figure 6 are replaced with achromatic colors.



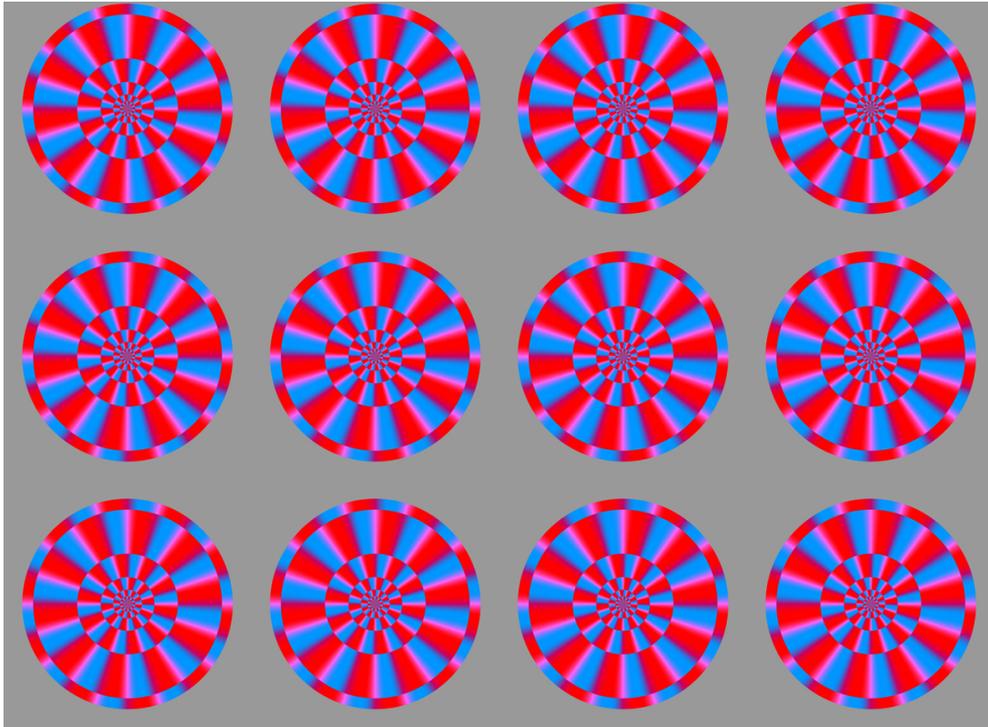
**Figure 9.** [In color online.] Supposed elements of the color-dependent Fraser–Wilcox illusion. (a) An image made up of long- and short-wavelength color regions sandwiching a thin strip that is darker than the two regions. (b) An image made up of long- and short-wavelength color regions sandwiching a thin strip that is brighter than the two regions. In a bright condition the darkest strip in (a) appears to move in the direction from the long-wavelength region to the short-wavelength one, while the brightest strip in (b) appears to move in the direction from the short-wavelength region to the long-wavelength one. In a dark condition the directions of illusory motion are just the reversals.

color region is red, the short-wavelength one is light purple, the darkest strip is purple, and the brightest strip is pink. In this regard, similar spatial arrangements between red and blue (figure 10a), red and green (figure 10b), or other color combinations all produce the illusions.

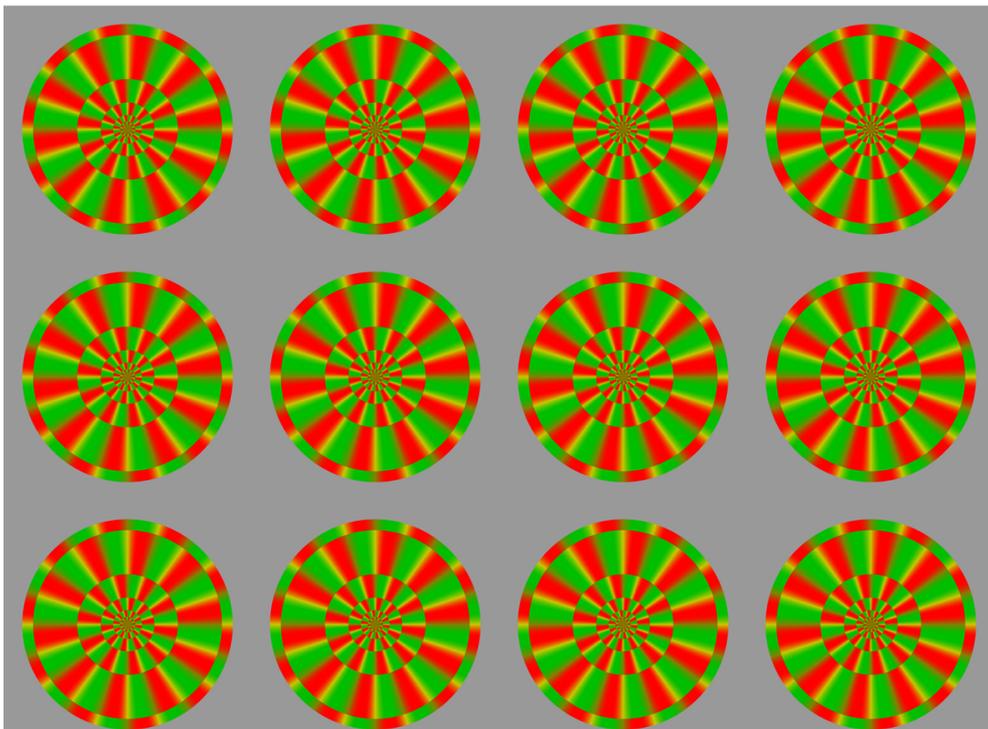
Yanaka and Hilano (2011) reported that these illusions could be triggered or enhanced by a blink, eye movement, or shaking the image. This characteristic appears to be unique to the color-dependent Fraser–Wilcox illusion.

### 3 Surveys

To confirm these observations I asked the audience of my talk about visual illusions delivered at the Shizuoka Science Museum (Shizuoka, Japan) to describe how they saw the illusion in figure 6 (without the number balloons) and figure 10a. These two images were printed at the highest quality using a printer, EPSON PX-5V, on a A4-sized sheet of paper: EPSON CRISPIA. One sheet and a questionnaire were given to each person; one hundred and one people participated in this survey. The independent variable was whether the room was bright ( $578 \pm 128$  lx) or dark ( $15 \pm 9$  lx). The participants were fully adapted to the dark condition before the survey. First, they observed the illusion images in the dark condition. Subsequently, they were light-adapted for a few minutes before they observed the illusion images in the bright condition. The participants were asked to report the direction in which the disks appeared to rotate, clockwise or counterclockwise. Only one participant (1%) reported no illusion all over the conditions; the others (99%) saw some illusory rotation. Except those who reported back-and-forth rotation or something irregular, eighty-nine participants reported either clockwise or counterclockwise rotation for each condition, and their data were analyzed further. Under the bright condition, more than half of the participants reported clockwise rotation, as shown in the upper block of table 1. On the other hand, under the dark condition, more than half of the observers reported counterclockwise rotation. These results confirmed the dimorphism of this illusion that depends on the lighting conditions.



(a)



(b)

**Figure 10.** [In color online.] The color-dependent Fraser–Wilcox illusion is observed in a variety of color combinations. (a) Combination between red and blue. (b) Combination between red and green. Each disk appears to rotate clockwise in a bright condition, whereas each disk appears to rotate counterclockwise in a dark condition.

**Table 1.** Results of the surveys conducted at a science museum, a university lecture, and a university seminar to ask the audience or students in which direction disks appeared to rotate.

	Reports	Bright condition/%		Dark condition/%	
		figure 6	figure 10a	figure 6	figure 10a
Science museum ( <i>n</i> = 89)	CW rotation	69	56	19	19
	CCW rotation	25	34	71	73
	no rotation	7	10	10	8
University lecture ( <i>n</i> = 72)	CW rotation	97	85	29	25
	CCW rotation	3	8	49	56
	no rotation	0	7	22	19
University seminar ( <i>n</i> = 11)	CW rotation	100	91	0	9
	CCW rotation	0	0	64	73
	no rotation	0	9	36	18

Note: CW: clockwise; CCW: counterclockwise.

Subsequently, the same survey was repeated at a lecture at the Ritsumeikan University (Kyoto, Japan). Seventy-two students participated; most of them were 19–22 years old. The independent variable was whether the room was bright ( $739 \pm 248$  lx) or dark ( $76 \pm 75$  lx). Contrary to the previous survey, the participants were fully adapted to the bright condition before the survey. First, they observed the illusion images in the bright condition. Subsequently, participants were dark-adapted for 5 min before they observed the illusion images in the dark condition. As a result, only one participant (1%) reported no illusion at all over the conditions; the others (99%) saw illusory rotation. Under the bright condition, the majority of participants reported clockwise rotation as shown in the middle block of table 1. On the other hand, under the dark condition, around a half reported counterclockwise rotation. These results confirmed the dimorphism.

Finally, the same survey was conducted in a seminar at the Ritsumeikan University in a more controlled condition. The room condition was whether the room was bright ( $882 \pm 118$  lx) or dark ( $4.5 \pm 1.6$  lx). Eleven students participated; ten were 20–22 years old and one was 47 years old. The participants were fully adapted to the bright condition before the survey. First, they observed the illusion images in the bright condition. Subsequently, they were dark-adapted for 5 min before they observed the illusion images in the dark condition. As a result, all the participants reported illusory rotation. Under the bright condition, the majority of participants reported clockwise rotation as shown in the lower block of table 1. On the other hand, under the dark condition, more than half of the participants reported counterclockwise rotation. Once again, these results confirmed the dimorphism.

#### 4 Discussion

These surveys verified the dimorphism of this illusion: the tendency to see the disks in figures 6 and 10a rotate clockwise under bright conditions while rotating counterclockwise in dark conditions. Moreover, some participants spontaneously reported back-and-forth rotation; this appearance can be explained by the idea that the two different motion illusions compete with each other.

However, the dimorphism was not confirmed by all of the participants. Some 39% participants did not report both illusions in the science museum survey, 47% did not for the university lecture, and 27% did not for the university seminar. It cannot be determined here whether these observers can see only one of the illusions or see both illusions under

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appropriate conditions. Empirically, most of people saw both illusions as long as I demonstrated these images person-to-person.

There remains a question. Which factor is essential, high/low luminance of stimuli or light/dark adaptation? In the survey at the science museum, observers were thoroughly dark-adapted and then they were light-adapted for just a short time. On the other hand, in the survey at the university lecture, observers were thoroughly light-adapted and then they were dark-adapted just for a short time. The former showed a larger proportion who reported counterclockwise rotation in the dark condition than the latter, whereas the latter showed a larger proportion who reported clockwise rotation in the bright condition than the former (table 1). These differences suggest a possible involvement of dark/light adaptation in the dimorphism.

To understand the mechanisms underlying the color-dependent Fraser–Wilcox illusion, it is necessary to explain the dimorphism that depends on lighting conditions. If we try to adopt a time-lag hypothesis (eg Backus & Oruç, 2005; Conway et al., 2005)—that motion illusion in a stationary image reflects apparent movement induced by the positional shift of some perceptual peaks depending on the difference in processing time—it is necessary to assume that the time lag should be reversed between bright and dark conditions. If we try to explain with an imbalance model (eg Murakami et al., 2006)—that miniature eye movement produces a stronger motion signal in a particular direction than in the opposite direction and this imbalance generates illusory motion—it is necessary to hypothesize that the imbalance should be reversed between the bright and dark conditions. Moreover, it is necessary to take into account the dependence on color. In this regard, a model including rod–cone interactions (Whitten & Brown, 1973), the Purkinje shift (Anstis, 2002), or chromatic aberration (Hartridge, 1918) is worth considering. These lines of approaches might reveal the mechanisms underlying the color-dependent Fraser–Wilcox illusion in the future. There are many studies on motion perception of chromatic stimuli (Cropper & Wuerger, 2005), to which this color-dependent motion illusion in a stationary image might contribute much because of its novelty.

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