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The confetti illusion

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Abstract

The Munker illusion, which produces two apparently different hues from a base color, can be extended to multiple apparent colors. By having foreground stripes in more than two colors, it is possible to create multiple foreground colors that lead to multiple apparent hues in the base objects. This technique works well for three colors and can be extended to four, six, and even ten colors.

Keywords: *Color illusion*; *Color assimilation*; *Color contrast*; *Munker illusion*; *Additive color mixing*

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In this paper, we extend the Munker illusion to produce more than two apparent hues from a single base color. Using multiple colors of foreground stripes, we present 'confetti' illusions in which a single base color appears as three, four, or even six hues. These differences in apparent color are due to shifts in apparent hue rather than being caused by differences in luminance. We review the relationship of the Munker illusion with other assimilation illusions and discuss how color assimilation combines with a third color to produce shifts in hue. We then present the confetti illusion and show that the effect of apparent changes in color is due to shifts in hue rather than differences in luminance. We provide examples, as shown in Fig. 1, of confetti illusions with three, four, and six different apparent hues, where each illusion has a unique hue for the base objects whose color seems to change.

Color assimilation illusions

Color assimilation illusions produce an effect where a background color appears to change in color space toward the additive mixture of an overlying pattern ('inducers'), such as stripes (Fach & Sharpe, 1986; Von Bezold, 1874). White (2010) noted two examples of this effect from the 1960s. Variants of this illusion include the Munker illusion (Bach, 2019; Munker, 1970) (see Fig. 2), the Monnier-Shevell illusion (see Fig. 5), the chromatic dungeon illusion, the dotted

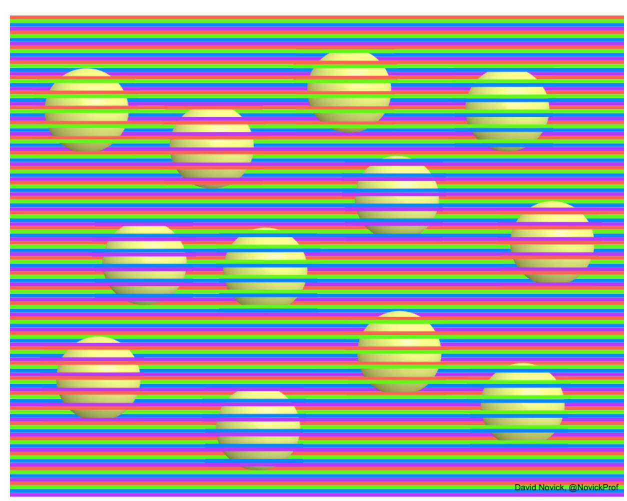

Fig. 1. Confetti illusion of four apparent colors. The spheres appear to be yellow, orange, light purple, and light green but are identical, with base color RGB 236, 255, 131. The stripes are RGB 250, 100, 85; RGB 115, 250, 40; RGB 30, 140, 255; and RGB 180, 060, 255.

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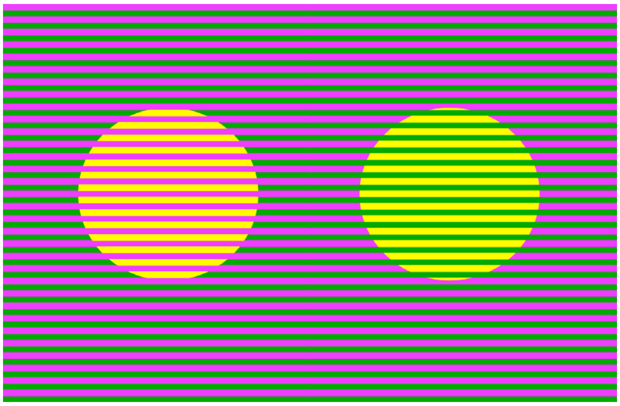

Fig. 2. Munker illusion: The background disks appear to be orange and greenish yellow but are actually of the same color (RGB 250, 255, 000). The inducer stripes are RGB 038, 171, 15 and RGB 234, 60, 255.

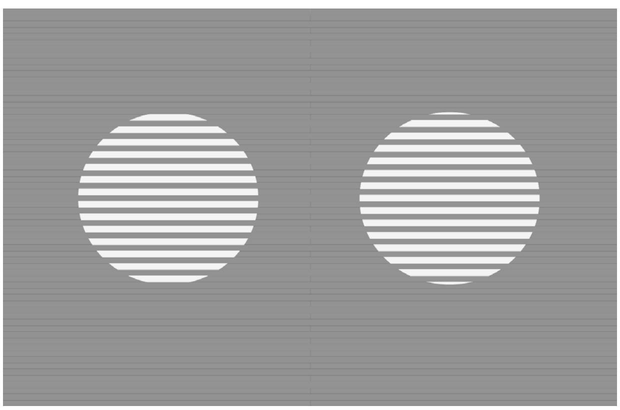

Fig. 3. The image from Fig. 2 desaturated in Preview to a monochrome image. The purple and green stripes shown in Fig. 2 appear here as stripes of gray with similar luminance.

color illusion, and the De Valois-De Valois illusion (Kitaoka, 2010) (see Fig. 6). These apparent shifts of hue depend strongly on the spatial structure of the color context (Monnier & Shevell, 2003). For example, the Monnier-Shevell illusion induces apparent shifts of hue in concentric circles (see Fig. 5). The difference between color assimilation illusions and White's effect is that color assimilation illusions produce a perceptible difference in hue as opposed to luminance, while White's effect is monochrome (White, 1979, 2010; see also Taya, Ehrenstein, & Cavonius, 1995).

As opposed to White's effect, the perceived difference in the Munker illusion in Fig. 2 is due to hue rather than luminance (although differences in luminance can enlarge the apparent differences). In the example shown in Fig. 2, the colors of the foreground stripes were chosen to have near-equal luminance. Fig. 3 shows the image in Fig. 2 in monochrome, in which it is apparent that the purple and green stripes have similar luminance. The Munker illusion can produce spectacular effects from relatively subtle differences in the colors of the inducers (see Fig. 4).

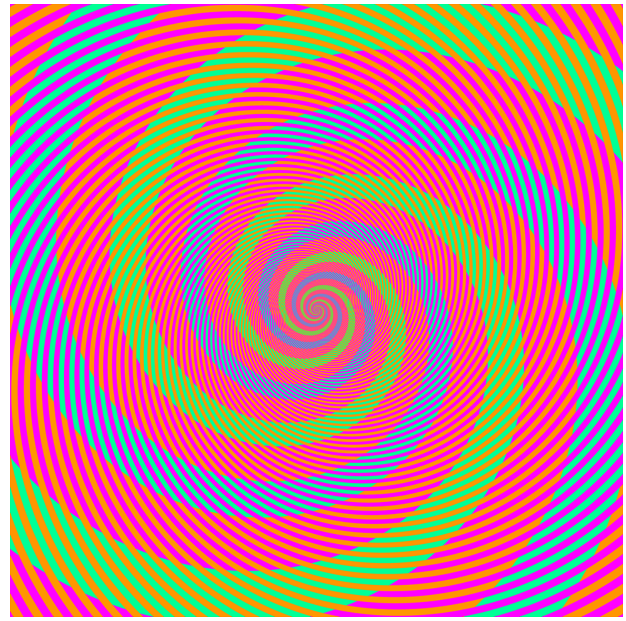

Fig. 4. Munker illusion where inducers are close in color and induce clearly different apparent hues in the target color. The apparently blue and green spirals are all the same color (RGB 000, 255, 150). The inducer stripes are RGB 250, 000, 255 and RGB 250, 150, 000.

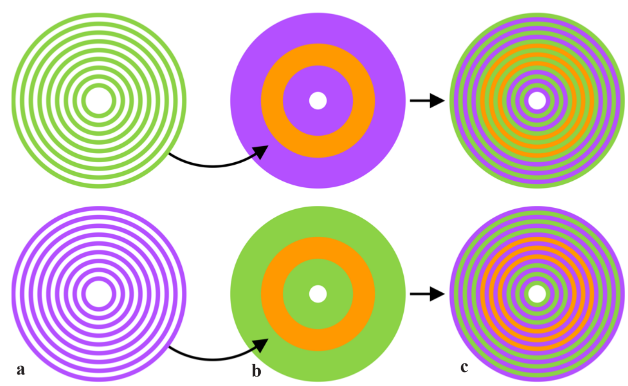

Fig. 5. Monnier-Shevell illusion showing different apparent hues produced by color contrast and color assimilation. Fig. 1a shows the inducer circles (RGB 144, 210, 074 and RGB 177, 080, 255). Fig. 5b shows the color-contrast effect for the target color (RGB 252, 152, 015). Fig. 5c shows the combination of the assimilation and contrast effects, in which the circles of the target color appear to be orange and pink.

The mechanism of the Munker illusion involves both a color-assimilation effect and a contrast effect. Fig. 5 is an example of the Monnier-Shevell illusion. The foreground circles (Fig. 5a) induce color assimilation and the adjacent circles (Fig. 5b) induce a color-contrast effect. The combined effects produce an apparent difference in color between identical sets of orange circles (Fig. 5c), with each of the foreground colors not adjacent to the target color being occluded by the target color. The same processes produce the apparent differences in hue of the Munker

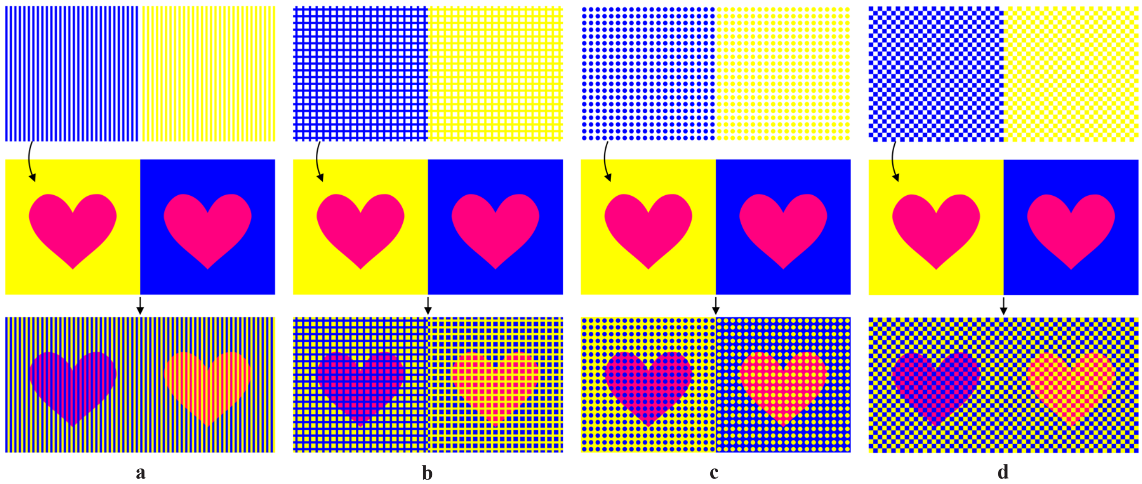

Fig. 6. Combined effect of color assimilation and color contrast in (a) Munker illusion, (b) chromatic dungeon illusion, (c) dotted color illusion, and (d) De Valois-De Valois illusion. In each illusion, the left heart appears to be magenta while the right heart appears to be orange. This occurs because each heart on the left appears to be bluer than the red target, because blue (assimilation) + blue (contrast of yellow) → blue induction. Each heart on the right appears to be more yellow than the target, because yellow (assimilation) + yellow (contrast of blue) → yellow induction.

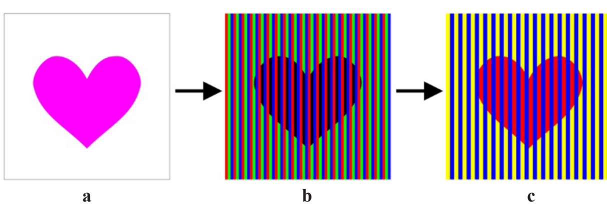

Fig. 7. Additive spatial color mixture. The yellow stripes of the surround in Fig. 5c are obtained by mixing the red and green stripes of the surround in Fig. 5b. The red stripes of the heart in Fig. 4c are obtained by mixing the red and black stripes of the heart shown in Fig. 5b.

illusion, the chromatic dungeon illusion, dotted color illusion, and the De Valois-De Valois illusion (see Fig. 6).

With respect to color assimilation, the Munker illusion can be understood as manifestation of the perception of spatial color mixing (Kitaoka, 2019), which is produced by additive color mixing (see Fig. 7). If the inducers become too far apart in the visual field (e.g. if the image is enlarged), then the color-assimilation effect no longer occurs. Conversely, if the inducers become too close together in the visual field (e.g. if the image is reduced in size and the patterns become very fine), then the effect is reduced to simple additive color mixing. The perception of spatial color mixing in the Munker illusion occurs when the color-assimilation effect seems to cause the colors of the stripes to 'bleed over' into the spaces between the stripes. This color assimilation effect is similar to the color-spreading effect for unconnected sinusoidal curves aligned in parallel (Sohmiya, 2007), the watercolor illusion (Pinna, Brelstaff, & Spillmann, 2001), and neon color spreading (Bressan, Mingolla, Spillmann, & Watanabe, 1997; Grossberg & Mingolla, 1985). Thus, in Fig. 8,

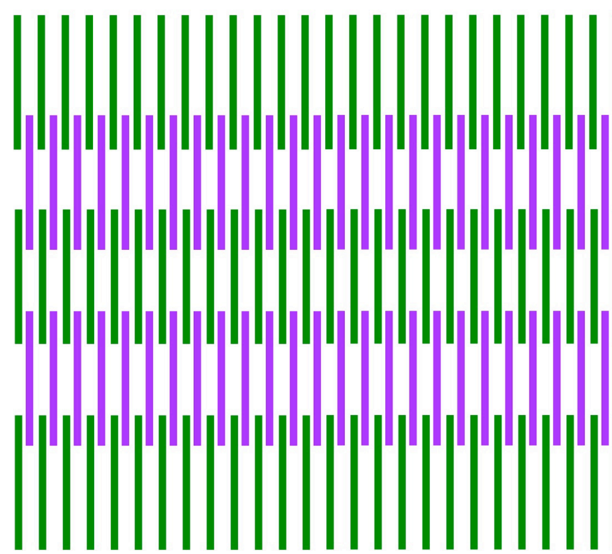

Fig. 8. Assimilation effect: The areas between the purple stripes appear light purple, and the areas between the green stripes appear light green. The strength of the effect is inversely proportional to the distance between the stripes, so reducing the size of the image will produce a stronger effect.

the areas between the purple stripes appear light purple, and the areas between the green stripes appear light green. When the image in Fig. 8 is placed on a yellow background, the spaces between the stripes are perceived as colors similar to the illusory colors shown in Fig. 2, as shown in Fig. 9.

The confetti illusion

The classic Munker illusion involves inducer foreground stripes of two colors leading to two apparently different

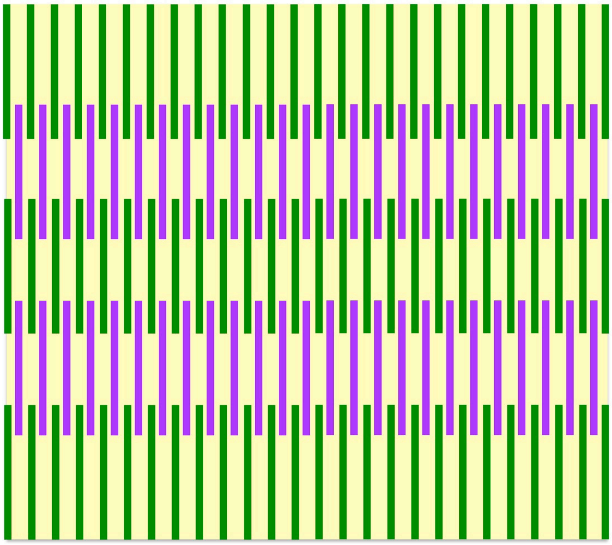

Fig. 9. The image in Fig. 8 is placed over a yellow background. The assimilation effect produces an illusory color difference similar to that in Fig. 2.

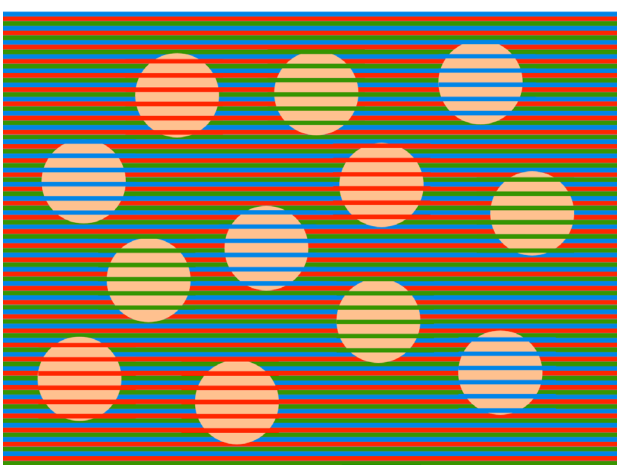

Fig. 10. Three-color confetti illusion: The background disks appear to be shades of pink, orange, and yellow but are actually all the same color (RGB 255, 192, 141). The inducer stripes are RGB 025, 136, 232; RGB 250, 033, 006; and RGB 065, 149, 011.

hues of a third, background color. (For purposes of clarity, we will call this third color the base color.) This lends itself to speculation that (1) foreground stripes of more than two colors could produce more than two apparently different hues of the base color and (2) combining foreground stripes could produce larger variations in the apparently different hues of the base color. Indeed, these extensions of the Munker illusion, which we term 'confetti' illusions because they feature disks of multiple colors, are possible, as shown below. While an image of the Munker illusion consists of foreground stripes of two different colors and presents two apparent colors, an image

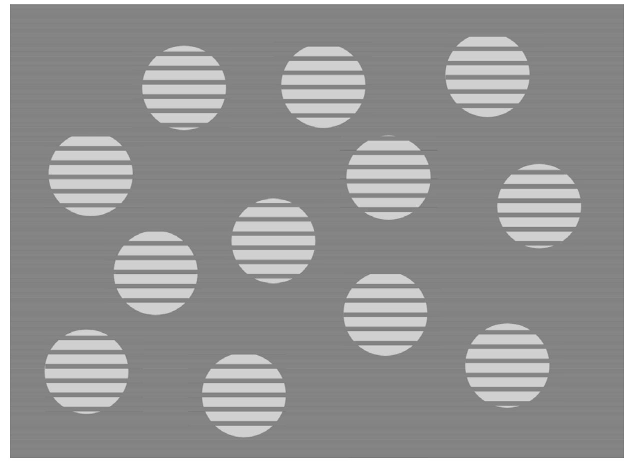

Fig. 11. The image from Fig. 10 desaturated with Preview to a monochrome image. The blue, red, and green stripes in Fig. 10 appear here as stripes of gray with similar luminance.

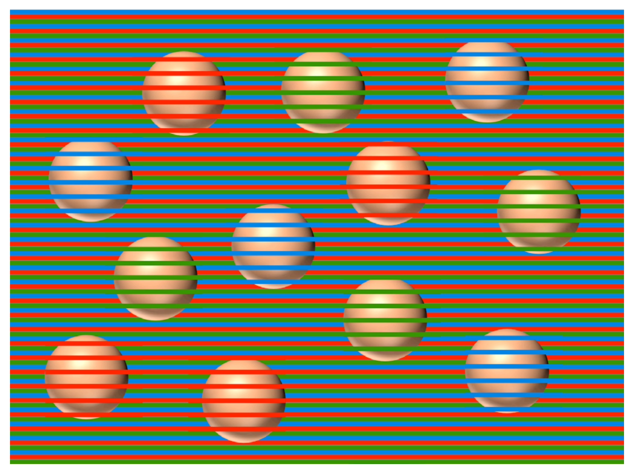

Fig. 12. The three-color confetti illusion in Fig. 10 rendered with the base objects as spheres. The base color of the spheres is the same as the color of the base disks shown in Fig. 10.

of the confetti illusion is made up of foreground stripes of multiple colors and presents multiple apparent colors.

Confetti illusions of three colors

With three colors of foreground stripes, it is possible to induce three different apparent colors in the base-color disk. The stripes are still close enough together to achieve the assimilation effect. For example, the disks in Fig. 10 appear to be shades of pink, orange, and yellow but are actually all are of the same color (RGB 255, 192, 141). These differences are due to the assimilation and contrast effects for color rather than White's effect of luminance, as all three foreground-stripe colors have similar luminance (see Fig. 11).

The apparent differences in hue of the base disks become even more striking when the base objects look like

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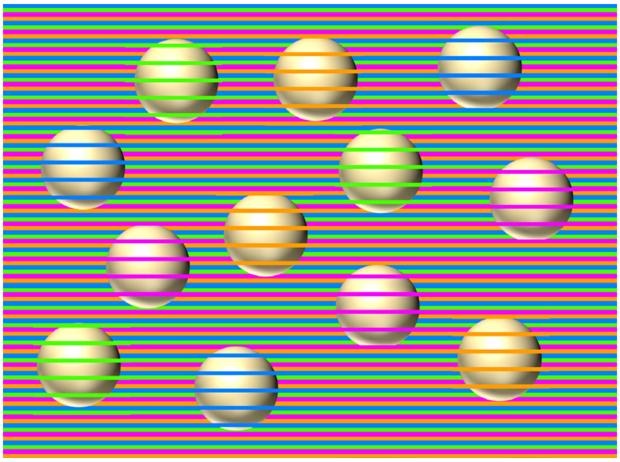

Fig. 13. Confetti illusion of four apparent colors with single-color inducer stripes. All the spheres have base color RBG 234, 235, 176. The inducer stripes are RGB 022, 129, 254; RGB 093, 255, 028; RGB 242, 000, 254; and RGB 252, 156, 016.

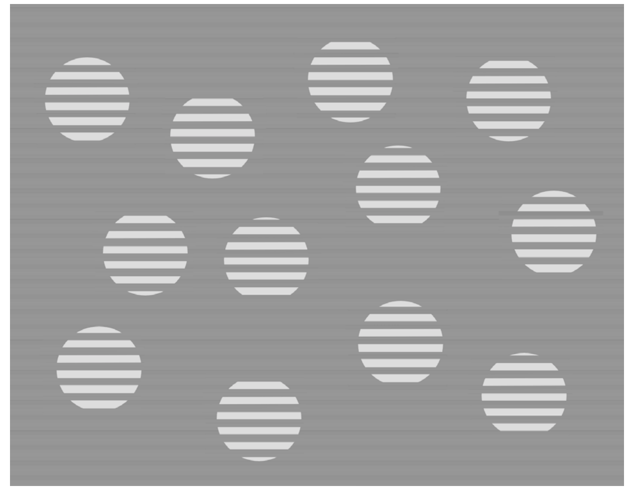

Fig. 15. The image from Fig. 14 desaturated with Preview to a monochrome image. The red, green, blue, and purple stripes in Fig. 14 appear here as stripes of gray with similar luminance.

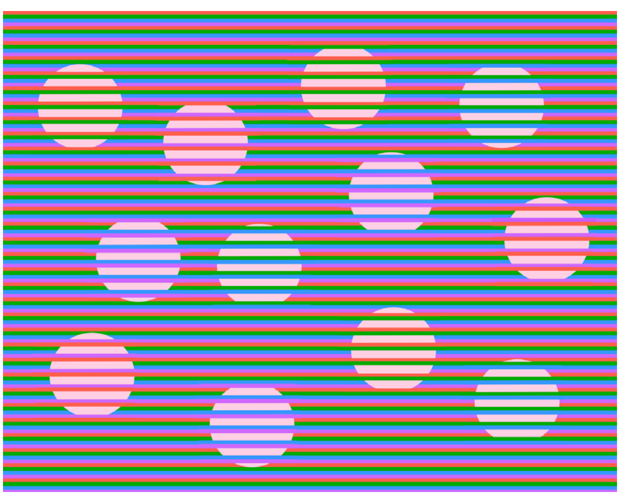

Fig. 14. Four-color confetti illusion: The background disks appear to be gold, pink, purple, and silver but are all identical, with base color RGB 255, 291, 214. The inducer stripes are RGB 256, 096, 080; RGB 038, 171, 015; 66, 152, 254; and RGB 204, 106, 254.

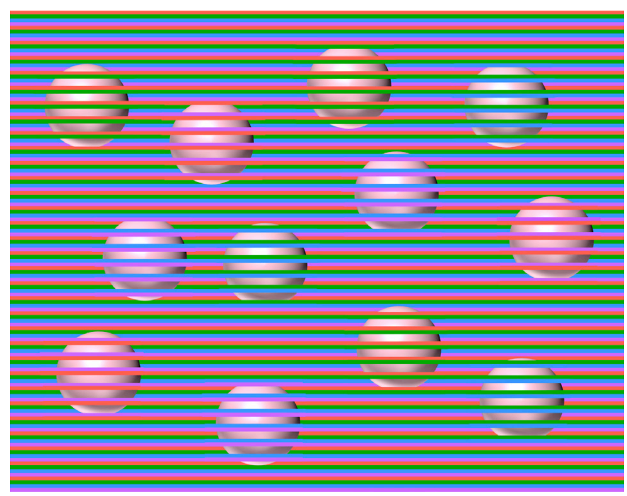

Fig. 16. The four-color confetti illusion shown in Fig. 14 rendered with the base objects as spheres. The base color of the spheres is the same as the base disks in Fig. 14.

spheres, as seen in Fig. 12. The reasons for this effect are not well-understood.

Confetti illusions of more than three colors

Our studies of the confetti illusion suggest that it is possible to extend the approach shown in Figs. 10 and 12 to a greater number of colors. For example, Fig. 13 has four apparent colors. But, as the number of colors of inducer stripes increases beyond five, the illusion progressively weakens because the width of the stripes shrinks relative to the size of the background shapes, thus decreasing the color assimilation effect.

However, it is possible to produce multiple combinations of inducer colors that lead to the appearance of multiple hues in the base color, while maintaining the strength of the illusion, by combining the foreground stripes into pairs. The spaces between the stripes remain small enough to produce assimilation effects, and the combination of two different colors of the stripes in effect creates a mix of the assimilation colors. In Fig. 14, for example, the combinations of red-green, red-purple, blue-purple, and blue-green stripes produce the appearance of four different colors of base-color disks. Again, this illusion is due to differences in hue rather than luminance, as indicated by Fig. 15. Fig. 16 presents the same confetti illusion with the base disks rendered as spheres.

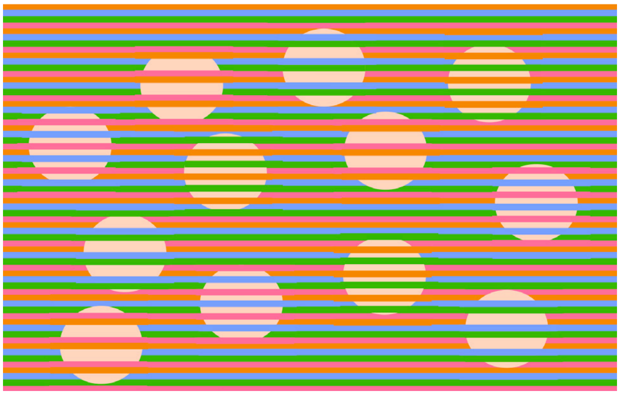

Fig. 17. Six-color confetti illusion: The background disks appear to six different hues but are all identical, with base color RGB 255, 212, 188. The inducer stripes are RGB 234, 137, 014; RGB 122, 161, 254; RGB 071, 187, 017; and RGB 251, 111, 156.

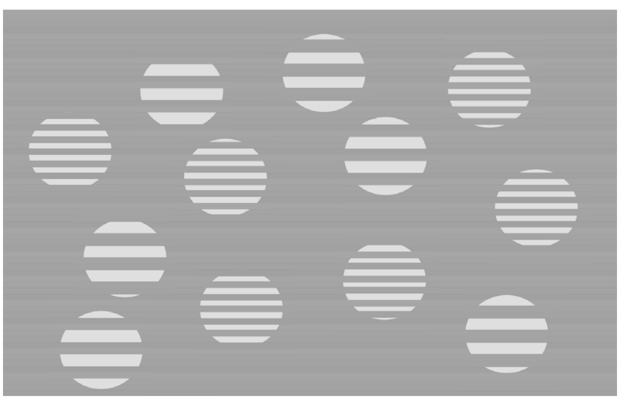

Fig. 18. The image from Fig. 17 desaturated with Preview to a monochrome image. The red, green, blue, and orange stripes in Fig. 17 appear here as stripes of gray with similar luminance.

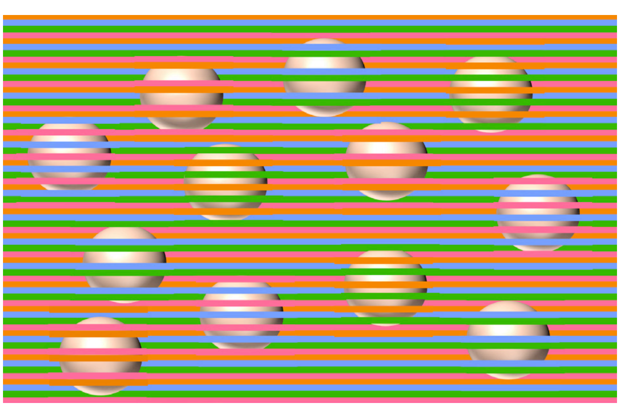

Fig. 19. The six-color confetti illusion in Fig. 17 rendered with the base objects as spheres. The base color of the spheres is the same as the base disks in Fig. 17.

With four colors of foreground stripes, more combinations of stripes are possible if the stripes are not adjacent. This enables creation of confetti illusions with an even greater number of different apparent hues in the base objects. For example, Fig. 17 shows a six-color confetti illusion. As shown in Fig. 18, the differences in apparent color are due to changes in hue rather than luminance. The apparent differences in color again seem more salient when the base objects are rendered as spheres, as shown in Fig. 19. Additional colors of stripes would produce even greater variations in the colors of the inducers. Ten different combinations of two stripes could be arranged from five colors, 15 different combinations of two stripes could be arranged from six colors, and so forth.

Discussion

Our work on the confetti illusion leaves or raises several questions about chromatic illusions. These include the relation of the confetti illusion with other chromatic illusions, why color differences seem more salient with spheres than disks, and the number of possible apparent colors.

The Munker illusion and its extension to the confetti illusion involve inducers in the form of parallel stripes. As noted in the 'Introduction' section, there are several related chromatic-shift illusions, all of which rely primarily on color assimilation, that have different forms of inducers and base colors. For example, in the Monnier-Shevell illusion (see Fig. 5), apparent shifts in hue are induced by adjacent concentric circles. With a sufficient number of different inducers, illusions in the Monnier-Shevell form could produce an arbitrary number of apparent colors from a single base color, forming a constellation of images of concentric circles with the same target color. Likewise, with a sufficient number of different inducers, a set of Munker illusions could also produce an arbitrary number of apparent colors from a single base color. The distinction of the confetti illusion is that it produces multiple apparent colors in a single illusion image rather than through a series of related but discrete, independent images.

As we noted in the presentation of Fig. 12, it is not clear why base-color spheres seem to lead to more salient apparent color differences than base-color disks. Indeed, the sphericity of the base images may not, in and of itself, cause the difference in perception. Rather, the gradients and variations of luminance that create the appearance of the spherical shape might affect the apparent colors. This remains an issue for future research.

In the 'Confetti illusions of more than three colors' section, we observed that confetti illusions with

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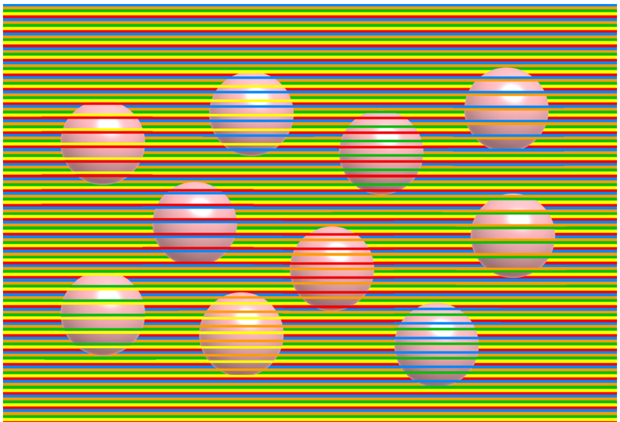

Fig. 20. Confetti illusion with ten apparent hues that can be distinguished upon close inspection but that do not stand out as all markedly different. The spheres have base color RGB 252 185 190. The inducer stripes are RGB 237, 000, 008; RGB 025, 136, 254; RGB 252, 156, 016; RGB 043, 189, 026; and RGB 255, 255, 030. However, this version of the illusion is the most striking version of a ten-hue confetti illusion that our studies were able to create, and some of the apparent differences are likely due to differences in luminance of the inducers (e.g. red and yellow vs. orange and yellow). This suggests that the differences among apparent hues diminish as the number of different inducers increases.

single-stripe inducers tend to lose power as the number of colors increases, and that using pairs of stripes of different colors can increase the number of colors of inducers. Using the paired-stripe approach, we have produced examples of the confetti illusion with six apparent colors, as shown in Figs. 17 and 19. Although this approach would enable creating confetti illusions with additional variations in colors of inducers, eventually the illusions would reach a point where the induced apparent hues had such minimal variation that it would be difficult to see them all as clearly different from each other. How many distinguishable colors could be induced remains an open question. Estimates of the number of colors that humans can distinguish range from tens of thousands to millions, and the number of perceptible hues is perhaps less than 200 (Masaoka, Berns, Fairchild, & Abed, 2013). This suggests that it would be possible to create confetti illusions with many different apparent colors. However, it is unlikely possible to induce the full range of apparent hues from a single target color other than white. And while our studies involving differences in the colors of inducers and target colors suggest that it is possible to create subtle differences in apparent hues, these subtle differences make the illusion somewhat less striking (see Fig. 20). So in practice, the number of possible apparent colors in a confetti illusion is likely to be much lower than the theoretical maximum.

Conclusion

In this paper, we extended the standard Munker illusion, which produces two apparently different hues from a base color, to multiple apparent colors. By having foreground stripes in more than two colors, and as long as the stripes remain spaced closely enough to induce color assimilation, it is possible to create multiple foreground colors that lead to multiple apparent hues in the base objects. All of these apparently different colors are due to color assimilation rather than due to differences in luminance, as in the Munker-White illusion.

This technique works well for three colors and can be extended to four, six, and even 10 colors. But as the number of apparent colors increases, the apparent hues in the base objects become more difficult to distinguish clearly as different hues.

Conflict of interest and funding

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