

REVIEW OPEN ACCESS

Black in Impressionism and Post-Impressionism: Art, Color Vision, and Psychophysics

John S. Werner^{1,2} 

¹University of Oxford, Department of Experimental Psychology, Oxford, UK | ²University of California, Davis, Department of Ophthalmology & Vision Science, Sacramento, California, USA

Correspondence: John S. Werner (jswerner@ucdavis.edu)

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ABSTRACT

From Paleolithic cave art to modern abstraction, artists have used black not merely as a neutral tone, but as a powerful perceptual tool. Among the earliest paintings, simple black outlines on cave walls prefigured a long tradition in which black provided structure, contrast, and expressive force. Impressionists and Post-Impressionists took divergent approaches: Renoir championed black as the “Queen of Colors” for its ability to intensify adjacent hues, while Divisionists such as Pissarro avoided it to encourage optical mixing. Van Gogh used black contours to define and energize forms by enhancing hue and saturation, and Malevich’s *Black Square* made achromatic contrast itself the subject of painting. These artistic choices can be understood through contemporary vision science. Black is not the absence of light, but the result of active neural contrast mechanisms that require preceding or surrounding illumination. Black and white form a unique achromatic axis, behave differently from chromatic colors, and are processed through parallel channels in the visual system. Dark borders—whether painted contours or physical frames surrounding an entire canvas—shape color appearance by preventing color spreading and isolating the artwork from its environment. By integrating art history with vision science, we show that Impressionist and Post-Impressionist artists have harnessed the same principles that vision research has described psychophysically.

1 | Paleolithic Origins

The visual arts originated with a single color—black. Some 35 millennia ago, fire permitted darkness to be conquered with light, but an additional benefit was the byproduct of the burnt embers yielding charcoal for drawings on cave walls. The most celebrated examples have been found in the Grotto Chauvet-Pont d’Arc in southeastern France (Figure 1, left). Radiocarbon dating estimates the drawings to be ~37000 years old, with the oldest ones only containing black borders [1]. Later cave paintings, such as in the Cave of Altamira in Spain, estimated to be about 13000 BC, show the black contours filled in with red ochre, a clay rich in iron oxide (hematite). Some of these artists even diluted their pigments to produce shading or chiaroscuro (Figure 1, right).

For at least 2,300 years, color theorists in art and science have burdened themselves with the question of whether black and white are colors [2]. Part of their arguments might have been avoided if Goethe’s [3] advice had been heeded: to analyze our *perception* of color, and as discussed in the next section, how black and white interact with each other to produce our color experiences.

Questions about whether black and white are colors are ill-posed. In normal discourse, one would not refer to black or white objects as colorless. That said, there are some properties of black that are noteworthy and differ from the chromatic colors, which are manifest in painting. As St. Clair [4] opined: “With black, things are always complicated” (p. 261).

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FIGURE 1 | Left: Rhinoceros etching on the cave wall in Grotto Chauvet-Pont d'Arc (Chauvet Cave, Public domain, via Wikimedia Commons). Right: Bison from the Cave of Altamira (courtesy of Museo de Altamira y D. Rodríguez).

2 | The Achromatic Color Series

Black and white form the extremes of an achromatic color axis. They are called achromatic because they contain no traces of hue, but they serve communication just like the chromatic colors. In the seminal work of Berlin and Kay [5], black and white were the only colors found in all languages that they studied. They concluded that in the first stage in the evolution of the color lexicon, there were two basic color terms, black and white, with additional color terms emerging in a systematic evolutionary sequence. Their original findings with 20 languages were confirmed and expanded by the World Color Survey that included 2616 informants speaking 110 languages [6]. In some cases, black and white might stand more generally for light and dark.

Figure 2 (left) illustrates the achromatic color series, which varies between black and white. A series of grays falls between the two extremes, ranging from black to dark grays, middle gray, and then lighter grays toward white. Figure 2 (right) shows the chromatic colors forming orthogonal hue planes to a central achromatic axis. Within each plane, complementary colors are arranged on opposite sides of the circumference. The center of gravity for mixtures of these hues coincides with the achromatic axis. It is for this reason that Ewald Hering [8, 9], in the last century, called these hues opponent. Thus, one cannot experience reddish-greens or bluish-yellows. A critical difference between the achromatic colors and the chromatic colors is that while the achromatic opponent colors cancel each other and cannot be experienced co-spatially or co-temporally, black and white do not do so. Black and white can mix to form a series of grays. They are, however, opponent spatially and temporally as we shall elaborate.

Moving from the central plane upward in Figure 2, colors become desaturated, and the hue circle shrinks. This is expected from Helmholtz's [10] observation that all colors, when raised in intensity, become desaturated and, at the limit, appear white. He demonstrated this to his own satisfaction by looking at the sun's disk through color filters. He specifically described how blue or yellow turns to white. On the other side of the central plane are the dark colors, produced by the addition of blackness. These colors are not experienced in isolation but are due to light–dark contrast.

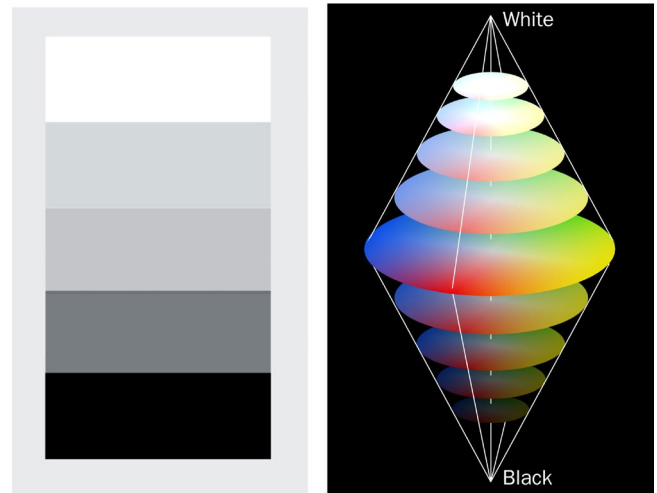


FIGURE 2 | Left: Achromatic color series forming gray levels between white and black. Right: Chromatic and achromatic colors with variations in black and white on the vertical axis. Orthogonal planes depict chromatic colors on the circumference, illustrated here for nine planes. Movements within this space are continuous [7].

While the luminance contrast (or luminance ratio between a region relative to its background) of elements within a painting is invariant with light level, our perception of contrast is not. This is illustrated by Monet's paintings of Rouen Cathedral, where the average reflectance of a bright sunlit facade (*Le portail soleil*) differs relatively little from the one that depicts dim early morning light (*Le portail, brouillard matinal*). This has also been demonstrated experimentally by Jameson and Hurvich [11] using a montage containing five achromatic patches varying from white to intermediate grays to black. Each stimulus was matched to a test spot as the overall illumination was increased. Importantly, not all patches increased in matching lightness as the illumination was increased. The white became whiter, while the black became blacker. They also reported that the intermediate gray levels changed much less with the illumination, demonstrating constancy as well as contrast. Indeed, these authors suggest that constancy is made possible by contrast with blackness and whiteness, balancing each other with respect to intermediate grays.

Goethe [3] emphasized the polarity of light and dark, white and black. He also anticipated Hering's opponent-colors theory when he indicated that paired colors interact with each other antagonistically. He came to this view by examining color interactions across space, as in colored shadows, and time, as in afterimages. Goethe further described how perceptual principles could be exploited to good effect in painting. J.M.W. Turner, professor of Perspective at the Royal Academy of Arts, studied Eastlake's [12] translation of Goethe's *Zur Farbenlehre*. Turner accepted much of Goethe's analysis of color experience and, in a tribute to him, painted *Light and Color (Goethe's Theory)—the morning after the Deluge*. Turner became extremely abstract in his later years and used dark colors more effectively than in his earlier work.

3 | Contrast Colors

From Leonardo [13] to the present [14], black has often been treated as due to the absence of light. Even Helmholtz [10] thought so, although his explanation was more nuanced, arguing that blackness is experienced in the absence of light, and the contrast colors occurring in the kind of configuration presented in Figure 3 (left) were due to what he called *unbewußte Schlüsse*—an unconscious judgment of the color in which one attempts to correct for the illumination causing the induction (a change in a stimulus color due to surrounding colors modifying the appearance). This history and his strident arguments with Hering [15] are chronicled in detail by Volbrecht and Kliegl [16].

The view that black is due to the absence of light is surprisingly widespread, but a simple experiment may convince otherwise. Cover your eyes in a dark room so that no light will reach your retina. Once adapted to complete darkness, one experiences a gray with random phosphenes (spots of light where

no physical light is present), commonly known as *Eigengrau*, *Augenschwartz*, or dark light. The punctate flashes are likely due to random photopigment isomerizations or random discharge of cells in the visual pathways because these cells have a resting discharge. One never experiences anything as black as in full illumination, even while objects that appear black reflect a great deal of light to the eye. This is illustrated by Renoir's 1874 painting *La Loge* (Figure 4, left). Unlike most Impressionists and many Post-Impressionists, Renoir used black liberally but only in daytime scenes. Compare that to Whistler's 1872 nocturne revealing shades of gray, but no black. These two paintings together support Leonardo's point that: "An object will display the greatest difference of light and shade when it is seen in the strongest light.... An object seen in moderate light displays little difference in its light and shade, and this is the case towards evening or when the day is cloudy" (quoted in ref. Isaacson, [13], p. 239).

Hering [15] and Mach [17] regarded dark colors as due to contrast from active processes of temporal and/or spatial contrast induction. Thus, the black and white (or light gray) of the painting in Figure 4 (left) are enhanced by the reciprocal spatial opponency whereby black is enhanced next to white and vice versa. Most of the colors that we experience are seen among other colors, and their appearance is modified by contrast. Some colors, such as black and brown, are experienced due to the presence of contrast and not the result of simply making them less intense; this only makes them dimmer. Instead, they occur as a result of preceding or surrounding stimulation. This can be appreciated from the simple demonstration in Video S1. If one takes a light that appears yellowish in a dark or dim background and then increases the intensity of a surrounding light, the appearance of the center passes through a series of colors, from yellow to light brown to dark brown, until, with further increases in surround intensity, the center will appear uniformly black. Once it becomes black, further increases in the surround intensity do not make it blacker.

Any color in the center of the configuration in Video S1 will become black, depending on the intensity ratio between the center and surround. One oddity occurs when the center is yellowish orange. While blue, green, and red centers become dark with increasing intensity of the surround, a yellowish-orange becomes brown, and most observers do not report it as a yellowish-black, but a color that is uniquely brown [18, 19]. Hering seems to have reached a similar conclusion when he wrote that the "Distinguishing feature of brown, namely, its blackness, never shows up clearly as an independent quality added to the yellow hue" (ref. [9], p. 58).

To probe the visual mechanisms subserving the perception of blackness, we [20] tested volunteers with a spatial configuration similar to that in Video S1. A central, white, test spot, slightly less than one degree in diameter, was surrounded by a monochromatic annulus with an outer diameter just over two degrees. The test and annulus were separated by a small gap—not a necessary feature of the stimulus, but one that seemed to make the task easier. The entire stimulus configuration was flashed for 500 ms with 10 s inter-stimulus intervals. The participant's task was to increase the intensity of the surround until the center just turned completely black. The sensitivity of the pathway mediating perception of blackness was assumed to be

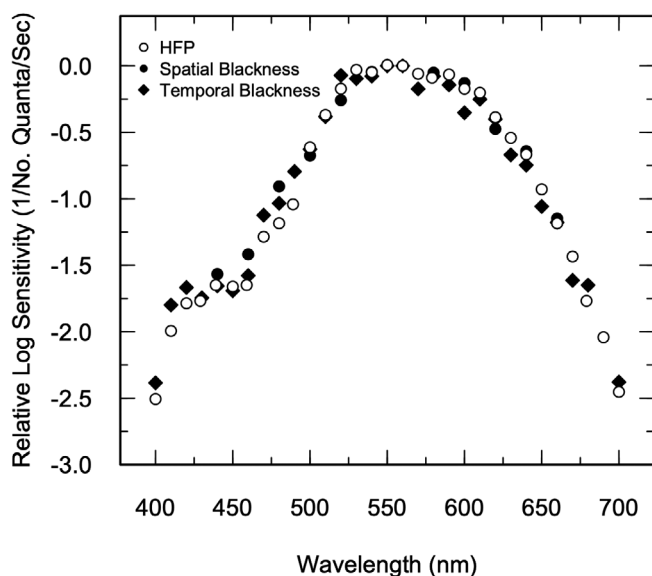


FIGURE 3 | Filled symbols show sensitivity (inverse of the number of quanta in the surround required to induce blackness in the center) for one observer plotted as a function of surround wavelength. Filled diamonds denote blackness induction with temporal contrast. Open circles denote data obtained from sensitivity to the annulus as a function of wavelength measured with heterochromatic flicker photometry (HFP).

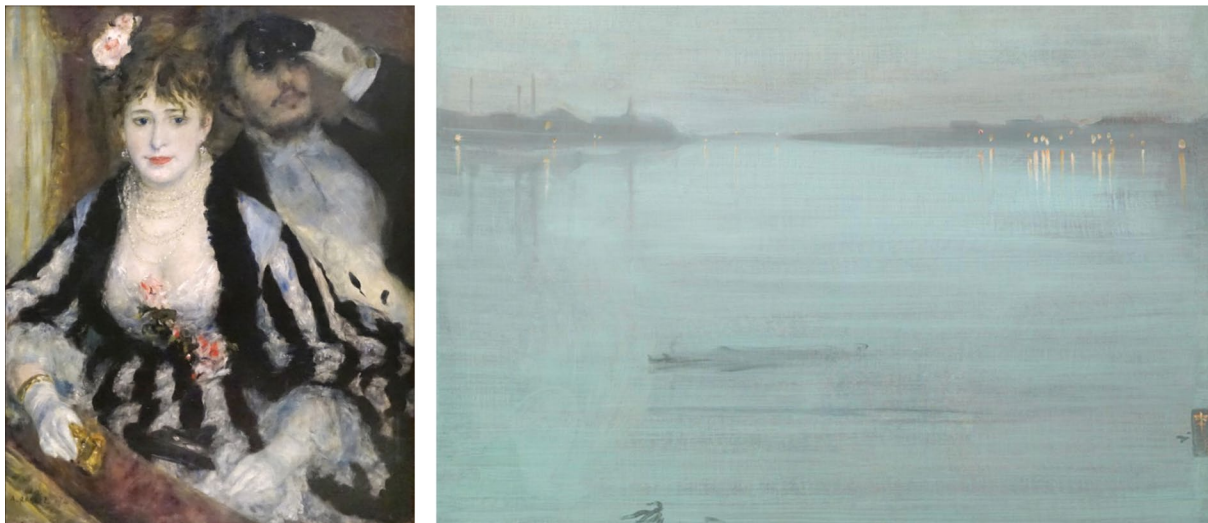


FIGURE 4 | Left: Pierre-Auguste Renoir, *La Loge*, Courtauld Gallery. Oil on canvas, 80×63.5 cm. Right: James Abbott McNeil Whistler, *Nocturne; Blue and Silver—Cremorne Lights* (1872). Oil on wood, 50×60 cm. Tate Britain.

related to the intensity of the monochromatic annuli required to induce complete blackness in the center. This quantity, the inverse of log number of quanta to induce 100% blackness, is shown in Figure 3 plotted as a function of wavelength for one observer. Under these conditions, the black center has a surface quality, but “Black as a phenomenon is ultimately revealed to be immensely nuanced and varied. It can range in intensity and uniformity, be luminous or matte.” (ref. [14], p.117). Most investigators have distinguished between the perception of black in the aperture or film mode versus the surface mode [21–24]. In a center-surround stimulus, black has a distinct surface quality, especially when the edges are sharp (contrast is high). When the edges are blurred, the central part may appear more like a shadow [25]. In our experiments, even though the stimulus configuration was projected into the eye using Maxwellian-view optics, sometimes called the aperture mode, when the criterion of complete black was reached, it was perceived to have a surface quality. This is the primary mode of appearance in painting.

Results for blackness induction were compared with measurements of spectral sensitivity using a procedure (heterochromatic flicker photometry or HFP) in which a monochromatic light was equated to a white standard. These data are plotted as open symbols for comparison with the inverse of spectral efficiency of blackness induction in Figure 3. The agreement between the two sets of data shows that the sensitivity to lightness or luminance is opposite to sensitivity to darkness throughout the visible spectrum.

The HFP task used to measure spectral sensitivity was chosen because it is thought to be mediated by a strictly achromatic process dominated by the additive activity of two of the three classes of cone photoreceptors, the cone receptors having maximal sensitivity at middle (M-) and long (L-) wavelengths [26]. The data can be modeled by summing L- and M-cone sensitivities. The agreement between the two sets of data is consistent with the idea that blackness induction is mediated by a surround mechanism that is purely achromatic. This is supported by tests of additivity with spectral mixtures [27]. Similar results were reported for a just-noticeable darkening [28] and by measuring

blackness with temporal induction; that is, the inverse log number of quanta for monochromatic lights to induce blackness onto a successively presented broad-band standard [29].

More complex results were obtained when the surround was a fixed white, and the center wavelength was varied [30, 31]. The resulting spectral sensitivity of the center indicated that the curve was not unimodal but had three lobes or “bumps” that resembled a brightness sensitivity function. Brightness mechanisms are known to combine signals from achromatic and chromatic mechanisms [32]. These chromatic influences are in the direction of inhibiting blackness [33]. Thus, while complete blackness results from activity due to achromatic contrast, chromatic signals may sometimes contribute to the percept before complete blackness is reached. This is most obvious in cases of dark colors such as brown.

4 | Area Contrast in the Art of Geometric Abstraction

In 1915, Kazimir Malevich exhibited his “Black Square” in St. Petersburg, Russia, at *The Last Exhibition of Futurist Art* (Figure 5). It was a radical rejection of representational art to focus on geometric form and color. His painting was displayed in a corner that was traditionally reserved for religious icons in



FIGURE 5 | *The Black Square*. Kazimir Malevich (1915) Oil on canvas. Tretyakov Gallery, Moscow.

Russian households. Curiously, it is not strictly black nor is it perfectly square, but that is a detail in the history of abstract art, for it inspired a movement in nonrepresentational painting which Malevich called “Suprematism.” Malevich painted four versions of the black square, along with other geometric forms such as a black cross and a black circle. All of them are surrounded by white areas necessary for area contrast (i.e., induction of blackness from white surrounds). Malevich, referred to black as “The zero point of painting” and he chose not to use frames, preferring instead to allow the white surround to merge or spread onto the surrounding white wall without restrictions [34].

Malevich’s black square inspired other avant-garde artists to paint abstract black images, including Robert Motherwell (*At Five in the Afternoon*, 1948–49), Franz Kline (*Painting No. 7*, 1962), Ad Reinhardt (*Abstract Painting No. 5*, 1962), and others. In 1991, the Museum of Modern Art in New York displayed a series of canvases from Ad Reinhardt created with small amounts of red, green or blue paint added to black paint. Hockney [35] commented how “You have to spend time with one of his pictures, physically in its presence. There’s no other way to experience it.... At first you perceive nothing; then bit by bit...you notice a delicate range of hues and tones” (p. 164). These artists have drawn attention to manifestations of basic visual processes of achromatic perception. The Reinhardt canvases apparently did not yield a perception of pure black, albeit something close. When the surround intensity (such as Figure 3) increases sufficiently, one experiences complete blackness regardless of the hue in the center [18]. Qualities such as gloss may also be noted in a painting, but are largely dependent on the illuminant direction and material properties of the surface. Pierre Soulages explored these properties with a technique that he called *Outenoir*, or beyond black [36]. He manipulated thickly sculpted mounds of black pigment using unconventional tools such as a spoon, a rake, and rubber to vary the textures on the canvas. The net result included surface areas that shifted dynamically between patches of reflected light and areas of absorption. Soulages became known as the painter of light and black. Earlier, Van Gogh studied the blacks in Dutch painting, notably the dark colors of Frans Hals and others, and said “One of the most beautiful things has been the painting of *black*, which nevertheless has *light* in it.” (ref. [37], p. 40). Soulages surely would have agreed.

5 | Spatial Scale of Chromatic and Achromatic Colors

While chromatic and achromatic colors are often difficult to separate perceptually in natural images, various digital processing techniques permit their image separation. Wright [38] demonstrated this with an image of van Eyck’s 1434 painting, *The Arnolfini Marriage*. By projecting a slide of the chromatic components in registration with a slide of the achromatic components, the appearance was a match to the original image. However, when the chromatic component was projected onto a uniform black field, the image was simply dim and did not resemble the original painting, again attesting to the importance of black–white contrast. This is but one more example of blackness resulting from contrast and not the absence of light.

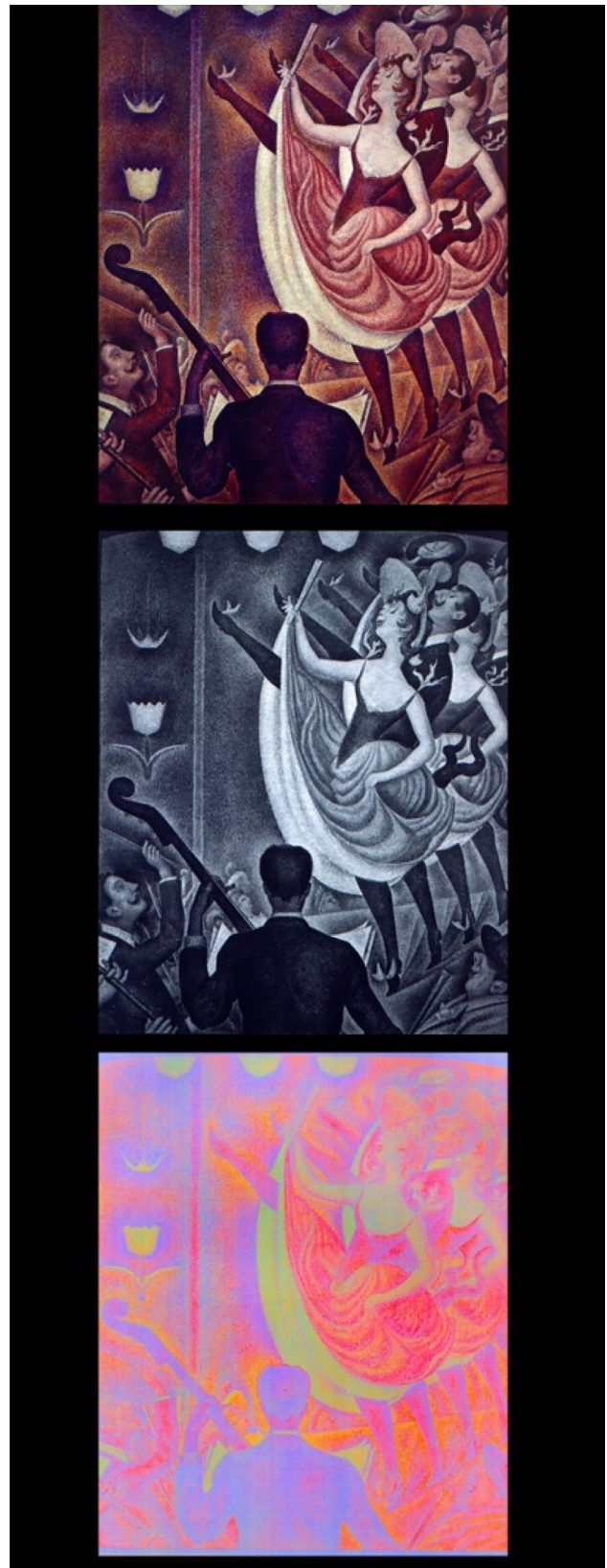


FIGURE 6 | Top: Georges Seurat’s, *La Chahut*, ca. 1889–1890. 1889–90. Oil on canvas, 171.5×140.5 cm. Collection of the Rijksmuseum “Kröller-Müller,” Otterlo, The Netherlands. Lower panels: the achromatic and chromatic components separated digitally. When combined, the result is the original image on the top (from 7).

Delacroix might have preferred the chromatic image. He said: “The enemy of all painting is gray” (ref. [39], p. 208), but the image is unnatural without its light–dark variations.

Further examples of the separation of chromatic and achromatic components of an image were shown by Werner and Ratliff [7]. In Figure 6, Seurat’s *La Chahut* is shown on the top left, while panels below show chromatic and achromatic components separated digitally. The areas of the original image that are brown contain orange in the chromatic image and black/white in the achromatic image. As might be expected from measurements of contrast sensitivity for different spatial scales [40, 41], the achromatic image contains more information about spatial detail (edges and borders) while the chromatic image contains information about larger areas or surfaces. The animation in Video S2 illustrates the effect of blur. When the chromatic and achromatic images are combined, blurring the chromatic image is barely evident in the combined image, but when the achromatic image is blurred, the combined image is dramatically degraded.

The parallel processing of chromatic and achromatic properties of an image by the visual system subserves our perception of objects. The fine detail in achromatic signals provides information about borders separating figure from ground, while the chromatic properties integrate/homogenize larger areas of a surface. Physiological studies demonstrate that the two types of signals are often multiplexed along the same optic nerve fibers from the retina to other areas of the brain [42].

An advantage of parallel processing of achromatic and chromatic variations is that natural images often have light–dark variations due to shadows and shading. The forms of objects may, therefore, be ambiguous from light–dark variations alone. Under these circumstances, however, chromatic information

may provide less ambiguous information to enable segmentation of objects from their backgrounds.

6 | Color Spreading Limited by Dark Contours

Color spreading to fill-in surfaces often occurs over long ranges and extends beyond the boundaries of the physical stimulus. This long-range assimilation may be shown by the watercolor effect in which a thin chromatic contour abuts a darker contour defining an enclosed white area. The previously white area will be filled with a desaturated color similar to the inside contour [43]. The watercolor effect has been quantified by color matching and hue cancellation. Devinck, Pinna, and Werner [44] showed that the watercolor effect may determine figure-ground relations in the perception of form when pitted against Gestalt factors such as closure, proximity, convexity, as well as amodal completion. An example is shown in Figure 7 (left) and perhaps helps us to understand the use of yellow interior borders to demarcate countries in some 17th-century maps. Spillmann [46] has also pointed out that this effect was already exploited in some Op-art works of Bridget Riley, such as her *Zing 2*. Figure 7 (right) shows Mondrian-like patterns from Spillmann to demonstrate watercolor spreading. He concluded that for this type of color spreading: “All that seems to matter is a dark–light edge profile” (p. 6). This can, however, sometimes also be achieved by an illusory contour [47].

Black contours prevent color spreading. This explains why black borders are seldom incorporated in paintings designed for optical mixing (i.e., in Pointillist painting) or color spreading (in Divisionism). Pissarro, who painted in both Impressionist and Post-Impressionist styles, has been quoted as saying that “Black should be outlawed by every painter worthy of the name” (ref.

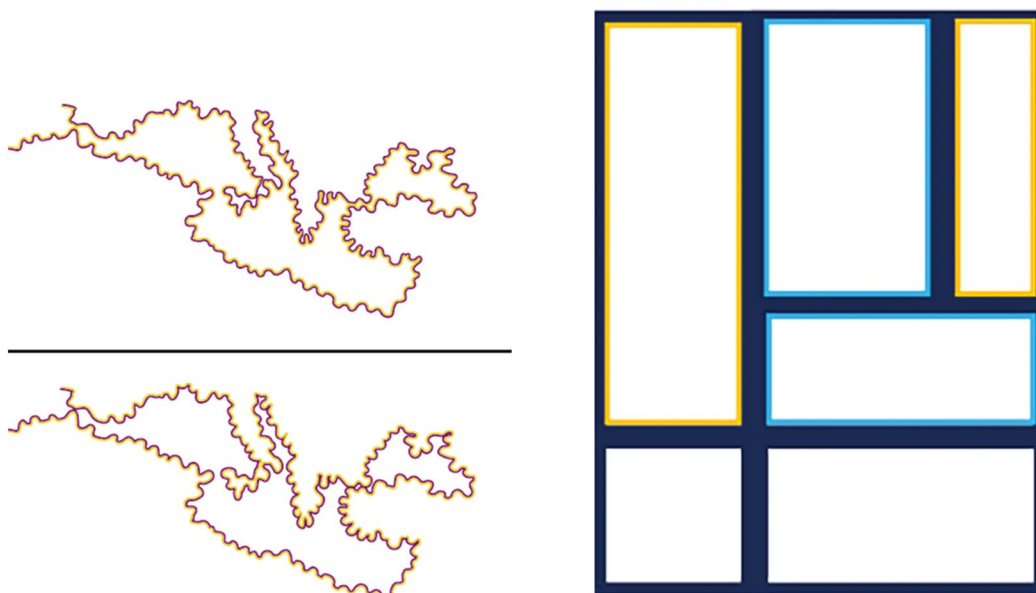


FIGURE 7 | Left: The watercolor effect occurs when a chromatic border fills in an area bounded by a darker contour. The form is facilitated by the filling-in, and therefore the map of the Mediterranean and Black Sea is immediately apparent in the bottom panel, but difficult to recognize when the contours are reversed as in the top panel (Design by Baingio Pinna in Werner et al. [45]). Right: The bottom panels illustrate the white area enclosed by a black border, while the upper panels show watercolor spreading when the same white surface is enclosed by an abutting chromatic contour (design by Frédéric Devinck in Spillmann [46]).



FIGURE 8 | Top: Vincent van Gogh, *Houses and Figure*. (1890) Oil on canvas, (52×40.5 cm) Barnes Museum, Philadelphia. Middle: Borders removed (annealing). Bottom: Black contours replaced by white contours.

[37], p.8). Signac made this point explicitly to Matisse when he spent the summer of 1904 with him in Saint-Tropez. In fact, many of Matisse's paintings use white contours instead of black. White is less effective in preventing color spreading and may decrease the saturation of hues owing to assimilation.

Renoir took a different position, calling black “the Queen of Colors.” This, as he noted, is because black borders make the chromatic colors more vibrant and intense by preventing color spreading. Renoir's comment predated the psychophysical study of the “gap effect.” When colors are close together spatially, there is a tendency for the border separating them to melt, rendering discrimination difficult. However, separating the colors with a small gap can improve color discrimination while making discriminations based on their luminosity more difficult [48].

Van Gogh used black contours effectively in his 1890, *Houses and Figure*, painted in the last year of his life in an asylum in Saint-Rémy-de-Provence, France. Compare his original canvas reproduced in the top panel of Figure 8 with the middle panel, in which the black contours are eliminated by annealing, and the bottom panel, where the black contours are replaced by white contours. There are several consequences of black borders in Van Gogh's painting. First and foremost, the black contours prevent optical blending beyond the areas that they enclose. For example, the dark green roof seems darker when it is surrounded by the black contours. Second, when the black contours are not present, the colors seem to blend together, so it is clear that the black contours help to define some clear-cut color patches, particularly because Van Gogh did not use highly saturated pigments in this painting, and the colors are not vivid enough (as demonstrated in the no-contour condition of the middle panel). Third, there appear to be assimilation effects when the borders are changed to white. For example, the red roof in the top panel looks more saturated when it is surrounded by a black contour, and it looks less saturated when it is surrounded by a white contour. A similar effect occurs for the “uniform” green roof just above (on the left side) the red chimney. These effects are consistent with the conclusion that black borders negatively impact a painting that depends on color blending, but positively affect paintings in which color mixing is eschewed.

7 | Further Thoughts About Borders—The Frame

The ultimate border in a painting is provided by the frame in which it is surrounded. It literally and metaphorically separates what the artist intended from the outside world. Consequently, the effects of contours and borders discussed above also apply to the frame itself. Today, collections of Impressionist and Post-Impressionist paintings are most often seen in ornate Louis XIV and XVI gilded frames. This was, in fact, a requirement for entries into the French Salon. Although such frames are beautiful, they do not always respect the period and the intentions of the artists. The frame was a point of contention for some Impressionists and Post-Impressionists. Renoir, for example, simply chose old frames designed for a previous era [49]. Degas designed simple frames for his paintings, sometimes gold, but often white, which he hoped would cast light onto the canvas. He worked closely with a frame maker at Maison Cluzel, located a few blocks from his studio in Montmartre. Degas was said to be upset when purchasers reframed his work. Monet

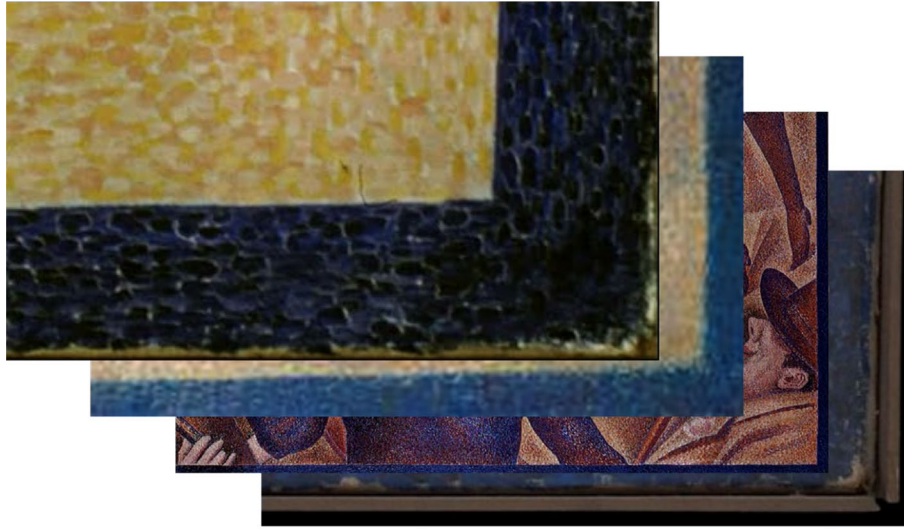


FIGURE 9 | Georges Seurat's frames shown (from top to bottom) for *Parade de Cirque* (1887–88), *La Chahut* (1889–90), *Jeune femme se poudrant* (1889–90), and *Le Cirque* (1890–91).

was inclined to frame more conventionally, in Baroque and Barbizon style, and he said that it was a trick by Degas to “make the frame complete the picture” [50]. In the sale of one of his pastels to Monet, Degas stipulated that he not change the frame.

The evolution of the frame in Impressionist and Post-Impressionist paintings paralleled the rebellion of these painters against classical traditions. How did it come about? The work of Chevreul was highly influential. As Director of Dyes at the Gobelins Tapestry works, he studied why black threads lost their vibrancy when placed next to certain other colors. His monumental work, *The Principles of Harmony and Contrast of Colors and their Application to the Arts* [51], described principles of simultaneous contrast in which he argued that the perceived differences between certain paired hues placed side-by-side will often be exaggerated and, most importantly, along borders. When two grays of different lightness are placed side-by-side, the lighter will appear even lighter and the darker will appear more dark, much as in the experiment of Jameson and Hurvich [11] already described.

The Post-Impressionists learned about Chevreul through Charles Blanc [52], who influenced Seurat, Signac, Gauguin, van Gogh, and others [53]. Chevreul commented on the importance of the frame in influencing the colors on the canvas. Pissarro, Signac, and Seurat initially chose white frames, but for the third Impressionists' exhibition, Pissarro chose frames with complementary colors to enhance hues in his painting [54]. Seurat experimented with the colors of his frames as well as with additional borders painted onto the canvas. For *La Chahut* (Figure 6), Seurat painted the original frame, with dots that had complementary colors to the main canvas. In 1888, Seurat began painting narrow borders in contrasting colors directly on his pictures and then added frames. Reframing required considerable effort because the canvases needed to be stretched, and a larger frame needed to be constructed. Sometimes he repainted his frames years after the painting was complete [55]. As

a result of his experiments, he settled on frames that were darker than the canvas that they surrounded. In most cases, they were nearly black, such as in his late figural paintings *Parade de cirque* (1887–88), *La Chahut* (1889–90), *Jeune femme se poudrant* (1889–90), and *Le Cirque* (1890–91). These frames are shown in Figure 9. From a vision science point of view, this may be expected as black encloses the canvas and separates it decisively from surrounding influences. Seurat described it in other terms, comparing his dark borders and frames to the newly introduced theatrical lighting of the Bayreuth opera house, whereby nearly all lights in the auditorium were extinguished to isolate the stage from any other distractions. A music critic described the Bayreuth stage as “like a brilliantly colored picture in a dark frame” (ref. [55], p. 127).

8 | Conclusions About Black in Painting

The color black is not experienced in darkness, but only in the presence of spatial and/or temporal contrast, as emphasized by Hering [15] and Mach [17] in the 19th century. More contemporary, quantitative work has shown that the spectral efficiency of inducing stimuli with a criterion of complete blackness follows the luminosity function [20, 29, 30]. Digital image separation of chromatic and achromatic colors in a painting, such as Seurat's *La Chahut* (Figure 6), illustrates that black effectively captures high spatial frequencies (edges and borders) while chromatic components of an image better capture low spatial frequencies contained in surfaces. Thus, black borders often tend to differentiate parts of an image while chromatic components tend to blur or homogenize a surface. This is illustrated strikingly by Pinna's watercolor effect [56].

Black has proven to provide a powerful perceptual tool throughout the history of painting, from the contours in Paleolithic cave art to modern art. Black prevents color spreading, and consequently was eschewed by many Impressionists and Post-Impressionists whose effects depended on optical mixing or

Divisionism. Conversely, by preventing color mixing, black borders may enhance the vividness of hues, as Renoir pointed out. Van Gogh also exploited this principle in many of his canvases by separating colors with thin black borders. Seurat recognized how dark borders enhance the vividness of hues that they enclose and chose frames for his canvases accordingly. The choices made by Impressionists and Post-Impressionists resulted in effects that could be anticipated from principles of vision science discovered around the same time by both artists and scientists.

Author Contributions

The author takes full responsibility for this article.

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Conflicts of Interest

The author declares no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Video S1:** Simulation of blackness induction: Double click on the yellow disc and as the white surrounding annulus increases in intensity, the yellow turns, beige, then brown and then black. **Video S2:** Animation: Double click the center to show the effect of blur separately for chromatic and achromatic components of the combined image. Blurring the chromatic component has little effect on the combined image, but blurring the achromatic component distorts the combined image.