
Guest editorial

Simultaneous contrast: the legacies of Hering and Helmholtz

“Thus if a pure white body is dotted with a dark-coloured paint by allowing small drops of the paint to fall on it, or if minute designs are made on it with this paint, the paint will look black or very dark; its distinctive quality will cease to be apparent and the eye will not be able to perceive its true colour. If marks are made with the same paint on a pitch-black body, the paint will look white or pale-coloured; its darkness will not be apparent and the eye will fail to perceive its true colour. If, however, this paint is placed in the midst of bodies that are not extremely white or extremely black, its colour will appear as it is and the eye will perceive its true colour in so far as it can be perceived by sight For the qualities of lights and colours are perceived by the eye only by comparing them with one another.”

Alhazen, *Optics*, circa 1025 AD,
from Sabra (1989a, volume I, page 99)

This account by the Middle Ages Arab natural philosopher Ibn Al-Haytham (circa 965 – 1040), known as Alhazen, is an early description of the phenomenon known as simultaneous contrast.⁽¹⁾ Although Alhazen’s description of simultaneous contrast was not the first—it was described by Aristotle—it is still remarkable, coming as it did more than six hundred years before Newton made his celebrated remarks in *Opticks* about the subjective nature of colour sensation. Newton, of course, went much further than Alhazen. While Alhazen assumed that objects themselves possessed colour which was radiated to the observer (Sabra 1989b), Newton understood that objects had only the capacity to selectively reflect light which alone could elicit a colour sensation. Nevertheless, Alhazen appreciated that colour appearance was in part due to mental processes. He assumed much of the perceptual content of vision was due to a faculty of judgement, involving a process called inference (Sabra 1978); simultaneous contrast results from judgements about the relative strengths of colours emanating from neighbouring parts of the scene.

I begin with Alhazen because his description of simultaneous contrast seems to anticipate key themes later developed by Helmholtz (1821–1894) and Hering (1834–1918) in their writings about the same phenomenon. It is with Helmholtz’s and Hering’s views on simultaneous contrast, and their modern expressions, that this editorial is primarily concerned, an appropriate topic as this issue falls between two special issues devoted to contextual effects on colour appearance. The idea that colour⁽²⁾ appearance involved the comparison of sensations from neighbouring image regions was a cornerstone of the work of Mach (1838–1916), but it was Hering who fully developed the idea that reciprocal interactions in the neural image determined much of surface colour appearance. On the other hand, Helmholtz gave clearest expression to Alhazen’s belief in the importance of judgement and inference in perception. Evidence for Helmholtz’s notion of ‘unconscious inference’ was provided by just those phenomena of simultaneous

⁽¹⁾ Alhazen’s description of simultaneous contrast was recently mentioned by Wade in the special Historical Issue of *Perception* (Wade 1996).

⁽²⁾ In general I will use the term ‘colour’ in its generic sense to mean either colour (chromaticity), lightness, or brightness, though where necessary I will use these terms individually. The reader will also forgive me for being somewhat cavalier in my use of the terms lightness (perceived reflectance) and brightness (perceived luminance). Space limitations prevent any discussion of the important but complex relationship between these two attributes.

contrast which Alhazen described so well nearly a millennium before. According to Helmholtz, simultaneous contrast was in most instances a deception of judgement, whereby observers judged the colour of a region as if it was covered by a veiling illumination the colour of its surround (Helmholtz 1866/1962). When applied to simultaneous brightness contrast, Helmholtz's theory states that a grey patch on a bright background is assumed to be more intensely illuminated than the same patch on a dark background, but because both patches reflect the same intensity of light, the former, by inference, must be of lower reflectance, and that is how it is perceived.

William James (1842–1910), in his classic work *Principles of Psychology*, provides a fascinating exposition and critique of Helmholtz's and Hering's views on simultaneous contrast. James summarised the two positions as follows:

"Helmholtz maintains that the neural process and the corresponding sensation also remain unchanged, but are differently interpreted; Hering, that the neural process and the sensation are themselves changed, and that the 'interpretation' is the direct conscious correlate of the altered retinal conditions. According to the one, the contrast is psychological in its origin; according to the other, it is purely physiological" (James 1890/1981, page 667).

Although few today would agree with James's distinction between a 'psychological' and 'physiological' explanation of simultaneous contrast, it is worth considering whether the views expressed by Hering and Helmholtz, which James believed to represent opposite theoretical poles on the issue, are reflected in today's opinion. I argue that Hering and Helmholtz anticipated different, but complementary, trends in today's explanations on simultaneous contrast.

Hering's ideas arguably lie at the root of the notion that surface colours are in part determined by local contrasts, or 'ratios', and that this ultimately leads to lightness and colour constancy. Hering stated:

"It is to reciprocal interactions in the somatic visual field that we owe, to a large extent, our visual acuity as well as the possibility of recognising objects by their colors" (Hering 1874/1964, page 124).

The link between contrast, brightness, and constancy was discussed in a number of seminal brightness matching studies, such as those of Hess and Pretori (1884/1970), Wallach (1948), and Heinemann (1955); and was central to the more recent work of Jameson and Hurvich (1964, 1989) and Hurvich and Jameson (1966). Today the link between contrast, brightness, and constancy is made in most undergraduate textbooks on vision (eg Sekuler and Blake 1990; Wandell 1995; and Goldstein 1996; see exact pages in the list of references below). Hering's reciprocal interactions, or 'lateral inhibition', are synonymous with the inhibitory subregions of today's spatial bandpass filters. Such filters, when incorporating a retinal-based gain-control mechanism, are widely assumed to transduce the pattern of local contrasts in the image. Such an assumption does not, however, imply that no further processing beyond the early filtering stage is believed necessary for surface colour perception. At the very least, local contrasts must be converted into surface colours by 'anchoring' them to an assumed colour or grey-level standard (Gilchrist et al 1996), and this may involve a mechanism which integrates local contrasts over whole regions of visual space (Land and McCann 1971; Arend 1994; Whittle 1994b). However, it is a testament to Hering that evidence continues to emerge to support his essential insight into the physiological basis of colour contrast and constancy. A notable example is the recent discovery of neurons in primate cortical area V4 that have small excitatory centres and large inhibitory surrounds (Schein and Desimone 1990). These neurons appear to have just the right sorts of properties for producing simultaneous contrast and colour constancy (Courtney et al 1995; see also Spillmann and Werner 1996).

What then of the legacy of Helmholtz's views on simultaneous contrast? Some investigators today give the same explanation as Helmholtz for at least some varieties of simultaneous contrast—for example as in Mollon's (1991) account of 'coloured shadows'. Coloured shadows occur whenever a region containing a shadow formed by partial occlusion of a coloured illuminant is also directly illuminated by a separate white light source. Although the shadow reflects only white light to the observer, it is seen in the complementary colour to the coloured illuminant which bathes its surround. Mollon, like Helmholtz, suggests that the whole surface, including the shadowed region, is assumed to be illuminated by the coloured illuminant. Thus the shadowed region must by inference be the complementary colour of the coloured illuminant if only white light is reflected from it. Mollon (1991) concludes that coloured shadows are thus a demonstration of colour constancy. Interestingly, he goes on to suggest that the computation of ratios at the edges of the shadow could implement such a colour constancy mechanism, a view that I have argued is identifiable with Hering rather than Helmholtz. Does this imply therefore that the Hering-based and Helmholtz-based approaches are really just two sides of the same coin?

The important difference between Hering's and Helmholtz's explanations of simultaneous contrast surely lies in the assumptions each makes about the nature of the colours defining the surround of the test region. In Hering's explanation, simultaneous contrast occurs irrespective of whether the surround of a test region is perceived to be part of a veiling illumination or a differently coloured material—the phenomenon is due simply to the effect of local contrast. Thus no assumption about the nature of the surround is, or need be, made. For Helmholtz, on the other hand, simultaneous contrast occurs *only because* the surround is assumed to be part of a veiling illumination; thus a specific assumption about the nature of the surround is being made. Helmholtz's view, unlike Hering's, leads one to expect that if the surround is clearly perceived *not* to be part of a veiling illumination, simultaneous contrast should not occur. William James came out in favour of Hering over Helmholtz precisely because he felt this prediction was not upheld. James cited, among other examples, the case of an alternating sequence of concentric grey and green stripes, in which the grey stripes appeared pinkish even though the green stripes could not plausibly be regarded as part of a veiling illumination covering the whole stimulus (James 1890/1981, page 672).

Although James was undoubtedly correct in arguing that Helmholtz was wrong to suggest that surrounds of isolated test regions are *in general* interpreted as veiling illuminations, Helmholtz can nevertheless be attributed with anticipating the many recent studies showing that simultaneous contrast can be more dramatic when surrounds are *unambiguously* seen to be so. When a test region is perceived to lie in a cast shadow, shaded region, or transparent overlay, its brightness is often greater than when it is surrounded by a surface differing only in reflectance from its neighbours (eg Gilchrist 1977; Adelson 1993; Gilchrist et al 1996; see also articles in the two special issues). It is as if the visual system partially discounted the *local* illumination when determining the brightness of the illuminated region. Such important demonstrations, which are part of a much wider repertoire of specific contextual effects on colour appearance (eg the Mach card demonstration; see also many beautiful examples in Koffka 1935), are arguably part of Helmholtz's legacy.⁽³⁾

Recent studies demonstrating the role of X junctions in helping distinguish illumination from reflectance borders (Adelson 1993) suggest that discounting *local* illumination changes may well involve more sophisticated mechanisms than those involved in

⁽³⁾It should be noted that Hering himself realised the importance of being able to distinguish between the effect on brightness of a cast shadow on a white surface, and the unaffected lightness of the surface. For Hering this ability clearly could not be accounted for on the basis of reciprocal interactions (Hering 1874/1964).

discounting *global* changes in illumination. If so, then Hering's and Helmholtz's theories may well represent the precursors of two types of complementary constancy mechanism. These are, respectively, a low-level mechanism which processes local contrasts to discount global changes in illumination (and which produces simultaneous contrast as an unwanted but inevitable side-effect), and an intermediate-level mechanism sensitive to specific feature configurations (such as X junctions) which discounts local changes in illumination.

Before leaving, I should point out that the views expressed here are by no means universally or even widely shared. Gilchrist, for example, echoing earlier arguments by MacLeod (1932), argues that both Hering's and Helmholtz's views on simultaneous contrast are essentially two sides of the same coin (Gilchrist 1994; and personal communication). According to Gilchrist the difference between Hering and Helmholtz is merely one of emphasis, with Hering emphasising more peripheral, Helmholtz more central mechanisms. Both adopt the same two-stage view of visual processing, an initial stage in which raw sensations are registered, followed by a second stage in which raw sensations are interpreted. For Gilchrist, the important distinction in evaluating theories of simultaneous contrast and constancy is not between Hering and Helmholtz, but between Gestalt (eg Gelb and Koffka) and non-Gestalt (eg Hering and Helmholtz) approaches. Gilchrist argues that the Gestalt psychologists rejected the very idea of a hierarchy of stages in perception, and were thus the true standard-bearers of the 'relational approach'—the view that surface colours and lightnesses are the result of encoding *relative* colour and luminance—which I have here identified as a legacy of Hering.

I hope this brief editorial, which reflects a different view from Gilchrist's, will contribute to an ongoing debate about the historical roots of theories of simultaneous contrast, as well as a debate about those theories themselves.

Fred Kingdom

McGill University, Montréal, Québec, Canada; e-mail: fred@jiffy.vision.mcgill.ca

Acknowledgements. I would like to thank the following persons who made useful comments on earlier versions of the manuscript, but I emphasise that their views are not necessarily the ones expressed here: Frans Verstraten, Abdelhamid Sabra, Alan Gilchrist, Lothar Spillmann, Paola Bressan, Leo Hurvich, Crystyn Williams, Barbara Blakeslee, Paul Whittle, and an unknown referee. This study was supported by grant MT 11554 from the Medical Research Council of Canada.

References

- Adelson E H, 1993 "Perceptual organization and the judgement of brightness" *Science* **262** 2042–2044
- Arend L E, 1994 "Surface colors, illumination, and surface geometry: Intrinsic-image models of human color perception", in *Lightness, Brightness, and Transparency* Ed. A L Gilchrist (Hillsdale, NJ: Lawrence Erlbaum Associates) pp 159–213
- Courtney S M, Finkel L H, Buchsbaum G, 1995 "Network simulations of retinal and cortical contributions to color constancy" **35** 413–434
- Gilchrist A L, 1977 "Perceived lightness depends on perceived spatial arrangement" *Science* **195** 185–187
- Gilchrist A L, 1994 "Absolute versus relative theories of lightness perception", in *Lightness, Brightness, and Transparency* Ed. A L Gilchrist (Hillsdale, NJ: Lawrence Erlbaum Associates) pp 1–33
- Gilchrist A, Kossyfidis C, Bonato F, Agostini T, Cataliotti J, Li X, Spehar B, Szura J, 1996 "A new theory of lightness perception" submitted
- Goldstein E B, 1996 *Sensation and Perception* 4th edition (Monterey, CA: Brooks/Cole) pp 153–156
- Heinemann E G, 1955 "Simultaneous brightness induction as a function of inducing- and test-field luminances" *Journal of Experimental Psychology* **50** 89–96
- Helmholtz H von, 1866/1962 *Treatise on Physiological Optics* volume 2, translated by J P L Southall (New York: Dover) pp 264–301 [originally published as *Handbuch der physiologischen Optik* (1866, Leipzig: Voss)]
- Hering E, 1874/1964 *Outlines of a Theory of the Light Sense* translated by L M Hurvich, D Jameson (Cambridge, MA: Harvard University Press) [originally published in 1874]

-
- Hess C, Pretori H, 1884/1970 "Quantitative investigation of the lawfulness of simultaneous brightness contrast" (translated by H Flock and J H Tenny) *Perceptual and Motor Skills* **31** 947–969 [originally published in 1884]
- Hurvich L M, Jameson D, 1966 *The Perception of Brightness and Darkness* (Boston, MA: Allyn and Bacon)
- James W, 1890/1981 *The Principles of Psychology* (New York: Dover) (originally published in 1890)
- Jameson D, Hurvich L M, 1964 "Theory of brightness and color contrast in human vision" *Vision Research* **4** 135–154
- Jameson D, Hurvich L M, 1989 "Essay concerning color constancy" *Annual Review of Psychology* **40** 1–22
- Koffka K, 1935 *Principles of Gestalt Psychology* (New York: Harcourt, Brace, & World)
- Land E H, McCann J J, 1971 "Lightness and retinex theory" *Journal of the Optical Society of America* **61** 1–11
- MacLeod R B, 1932 "An experimental investigation of brightness constancy" *Archives of Psychology* **135** 5–132
- Mollon J, 1991 "The tricks of colour", chapter in *Images and Understanding* Eds H Barlow, C Blakemore, M Weston-Smith (Cambridge, England: Cambridge University Press)
- Sabra A I, 1978 "Sensation and inference in Alhazen's theory of visual perception", in *Studies in Perception: Interrelations in the History of Philosophy and Science* Eds P K Machamer, R G Turnbull (Columbus, OH: Ohio State University Press)
- Sabra A I, 1989a *The Optics of Ibn Al-Haytham* volumes I and II (London: The Warburg Institute)
- Sabra A I, 1989b *Zeitschrift für Geschichte der arabisch-islamischen Wissenschaften* **5** 115–140; reprinted with identical pagination "Form in Ibn Al-Haytham's theory of vision", in A I Sabra *Optics, Astronomy, and Logic* chapter XI (1994, Aldershot, UK: Varorium)
- Schein S J, Desimone R, 1990 "Spectral properties of V4 neurones in the macaque" *Journal of Neuroscience* **10** 3369–3389
- Sekuler R, Blake R, 1990 *Perception* 2nd edition (New York: McGraw-Hill) pp 77–79
- Spillmann L, Werner J S, 1996 "Long-range interactions in visual perception" *Trends in Neuroscience* **19** 428–434
- Wade N J, 1996 "Descriptions of visual phenomena from Aristotle to Wheatstone" *Perception* **25** 1137–1175
- Wallach H, 1948 "Brightness constancy and the nature of achromatic colors" *Journal of Experimental Psychology* **38** 310–324
- Wandell B A, 1995 *Foundations of Vision* (Sunderland, MA: Sinauer Associates) pp 288–290
- Whittle P, 1994 "Contrast brightness and ordinary seeing", in *Lightness, Brightness, and Transparency* Ed. A L Gilchrist (Hillsdale, NJ: Lawrence Erlbaum Associates) pp 111–157