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# The Ehrenstein Illusion

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## **Abstract**

The original Ehrenstein illusion was first described by Walter Ehrenstein *senior* (Ehrenstein, 1941, 1954). It is generated by a configuration of four line segments which induce the perception of a so-called illusory figure at the centre of the configuration (Fig 1a). This illusion is part of a class of visual perceptual phenomena referred to as contrast or brightness illusions.

## **Introduction**

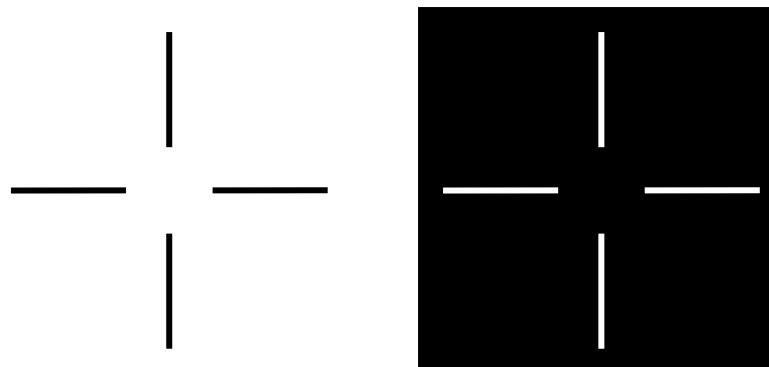
The original Ehrenstein illusion was first described by Walter Ehrenstein *senior* (Ehrenstein, 1941, 1954). It is generated by a configuration of four line segments which induce the perception of a so-called illusory figure at the centre of the configuration (Fig 1a). This illusion is part of a class of visual perceptual phenomena referred to as *contrast or brightness illusions* (e.g. Spillmann, 1977), as for example the Hermann grid illusion (Ehrenstein, 1941; Spillmann, 1994; Schiller & Carvey, 2005) or the so-called Mach band phenomena (Mach, 1865; Fiorentini, 1972). It has been assumed that the Ehrenstein illusion might be a particular case of simultaneous contrast (e.g. Spillmann, Fuld, & Neumeier, 1984), a subjective contrast phenomenon where surfaces surrounded by regions of opposite contrast polarity appear brighter or darker than they are according to psychophysical measurement (e.g. Fiorentini, 1972). Illusory figures, however, are phenomenally different from simultaneous contrast displays and may produce subjective contrast effects that are considerably more pronounced.

## **Phenomenal characteristics**

The most salient phenomenal attribute of the Ehrenstein illusion is the apparent brightness enhancement at the centre of the configuration, the latter being systematically perceived as brighter (Fig 1a) or as darker (Fig 1b) than the general background, the

brightness enhancement effect being more pronounced than the darkness enhancement (Spillmann, Fuld, & Gerrits, 1976). These asymmetrical perceptual sensations of brightness/darkness enhancement or subjective contrast are considered illusory because they have no physical origin, given that the luminance at the centre of the figure is strictly identical to the background luminance.

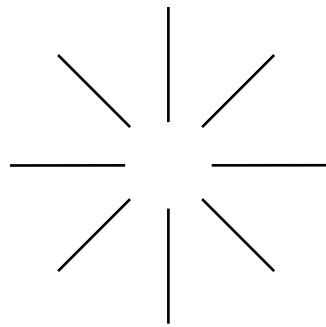
Perceptions of structural depth (Coren, 1972) and figure-ground segregation (Kennedy, 1978; Spillmann & Dresch, 1995; Watanabe, Nanez, & Moreno, 1995) are combined with the apparent brightness enhancement in several variations of the Ehrenstein illusion. A phenomenal description or perceptual hypothesis based on a cognitive interpretation of the illusion (Rock, 1987; Parks, 1986) as it occurs in the classic configurations shown here below (Figs 1a and 1b) may be given in terms of “a cross structure that is partially occluded by a surface at its centre”.



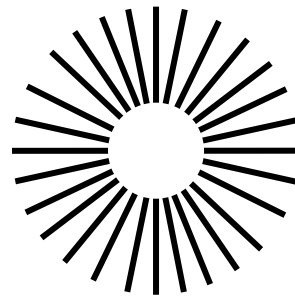
**1a)**

**1b)**

Variations of the Ehrenstein illusion have been generated (Fraser, 1983; Prazdny, 1983, 1985; Parks, 1982; Salvano-Pardieu, 2000; Pinna, Ehrenstein, & Spillmann, 2004) to show how local characteristics of the configuration may influence this illusion, inducing the perception of a diamond-like surface at the centre as shown above (Fig 1a), that of a more square-like shape (Fig 1c), or a disk (Fig 1d).



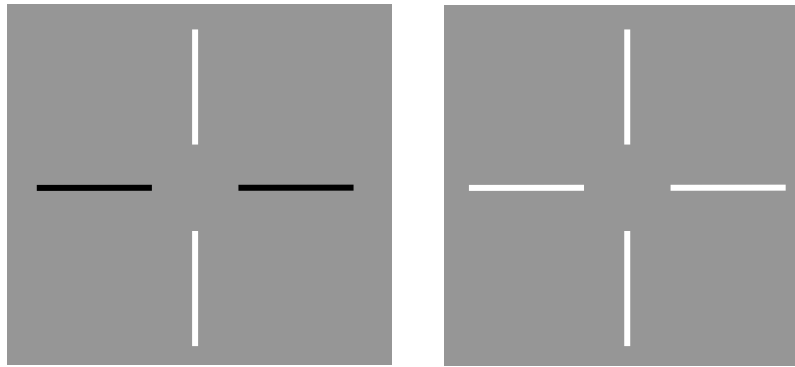
1c)



1d)

The strength or magnitude of the brightness enhancement perceived in the Ehrenstein illusion depends on *geometric factors* such as the length of the inducing lines and the central gap size (Fraser, 1983; Bradley & Mates, 1985; Salvano-Pardieu, 2000). An interaction between the length of the inducing lines and the size of the illusory surface at the centre in the formation of this brightness illusion was found, with a spatial limit corresponding to a gap size of about 2.4 degrees of visual angle below which the brightness illusion is always perceived, regardless of the length of the inducers. The strength of this perception was found to increase linearly with increasing values of a so-called area ratio, defined in terms of the ratio of the area of the ring formed by the four inducing lines (Salvano-Pardieu, 2000). As to illusory contours surrounding the central brightness enhancement, hypotheses about geometric parameters relative to some ratio between the physically specified and the illusory edge length have been forwarded (Leshner & Mingolla, 1993; Shipley & Kellman, 1992).

Local changes in the *contrast polarity* of the inducing lines in configurations of the Ehrenstein type and similar displays are yet another factor which influences the strength of perceptual sensations of apparent brightness enhancement, surface formation, and figure-ground segregation (Day & Jory, 1980; Prazdny, 1985). Studies of subjective brightness differences in Ehrenstein figures as a function of the contrast polarity of the inducing elements (Dresp, Salvano-Pardieu, & Bonnet, 1996) have shown that brightness differences are still perceived in Ehrenstein figures with inducers of opposite contrast polarities (Fig 2a). However, the frequency with which such perceptions occur is significantly lower and the times to make a decision are noticeably longer than with Ehrenstein figures where all inducers have the same contrast polarity (Fig 2b).



**2a)**

**2b)**

Investigations into possible links between the Ehrenstein illusion and other subjective contrast phenomena, such as so-called *neon colour spreading* (Redies & Spillmann, 1981; Redies, Spillmann, & Kunz, 1984) have suggested similar underlying mechanisms. Differences in behavioural correlates of the brightness/darkness enhancement in the centre of the displays and the illusory contour which may enclose the area which exhibits this apparent contrast indicate that the formation of the subjective contour may be generated by perceptual mechanisms that are independent from those underlying the subjective surface phenomenon (Ware, 1981; Dresch, 1992; Dresch & Grossberg, 1997; Dresch, Salvano-Pardieu, & Bonnet, 1996). Other perceptual phenomena such as apparent motion and stereopsis (Ramachandran, 1985, 1986) or tilt and motion aftereffects (Smith & Over, 1975; 1979) have been linked to displays exhibiting subjective surface contrast and illusory contours, including the Ehrenstein illusion, which was found to be subject to an apparent displacement phenomenon when combined with random-dot motion effects (Spillmann & Redies, 1981).

The luminance detection of small line targets flashed on the virtual line which defines the shortest distance between two inducing lines of the classic cross-like Ehrenstein configurations was found to be improved compared with other target locations (Dresch & Grossberg, 1997; Salvano-Pardieu *et al*, 2006). Such detection facilitation is generally referred to as spatial facilitation (Morgan & Dresch, 1995; Kapadia *et al*, 1995; Yu & Levi, 1997) and the fact that it may be produced to a greater or lesser extent by line configurations such as the Ehrenstein illusion has been explained on the basis of a general sensitivity of spatial facilitation phenomena to the luminance intensity or contrast of the inducing lines (Wehrhahn & Dresch, 1995), to their relative length, contrast polarity, and co-linearity (Dresch

& Grossberg, 1997; see also Dresch, 1999 or Polat, 1999, for extensive reviews) and the fact that an effective visual context reduces spatial uncertainty about the location of a luminance target in the visual field (Morgan & Dresch, 1995; Salvano-Pardieu *et al*, 2006). The different phenomenal characteristics and behavioural correlates of subjective surface contrast and illusory contour formation in the Ehrenstein illusion have produced different theoretical accounts or explanations of this phenomenon.

### **Theoretical accounts**

*Cognitive theories* of perception (Gregory, 1972; Rock, 1987) suggest that visual processing of illusory contour figures operates generally and predominantly through *top-down* processing. Such processing is to enable the perceptual system to resolve stimulus ambiguities in the most plausible manner by exploiting learnt knowledge about our physical environment. Such knowledge produces the rules of perceptual organization that govern our way of seeing the outside world. Since objects in natural biological environments are often camouflaged, partially hidden, or occluded, perceptual cognition has “learnt” to rely on statistically driven problem solving processes to restore potentially important information about shape surfaces and object contours that may be lacking in the physical environment or stimulus. In the case of the Ehrenstein illusion, such problem solving (Rock, 1987) would generate a perceptual hypothesis or cognitive interpretation, as mentioned above, in terms of a disk-shaped surface superimposed on a cross, giving rise to the apparent contrast effect that is seen in the centre of the display at the physical gap between the radial inducing lines. Such a perceptual interpretation gives the stimulus a definitive and plausible meaning and accounts for apparently missing object parts by suggesting that the inducing lines would “continue” behind the disk.

*Gestalt theory* attributes the perception of illusory brightness and contours to visual perceptual processes that are directly determined by the physical stimulus. The *Gestalt* approach invokes principles of perceptual organization such as *Good Continuation* or *Prägnanz*, which are *stimulus-driven*. The latter do not require a cognitive interpretation of physical structure as such, but rely essentially on the intrinsic coherence of the visual processing of physical structure. The Gestalt postulate that is most often invoked to explain why we are bound to see illusory figures as in the Ehrenstein illusion is *amodal completion* (e.g. Kanizsa, 1979; Purghe & Coren, 1992). It describes a hypothetical process where a local area of the visual field that receives no physical input is perceptually completed through

*bottom-up* visual mechanisms that are directly determined by the local structure of the stimulus. Using variants of the Ehrenstein figure (see, for example, Pinna, 1996), researchers investigated whether and how illusory contour and surface formation are affected by cognitive or symbolic cues in the absence of a stimulus structure that would suggest perceptual completion, that is when the radial inducing lines of the Ehrenstein figure are replaced by radial arrangements of letters of the alphabet, for example (Pinna, Ehrenstein, & Spillmann, 2004). The perception and recognition of the letters implies their completeness as independent symbolic entities and illusory figures should not be perceived in the central part of such radial arrangements according to theories that invoke apparent incompleteness as determining factor. The findings revealed that perceptual incompleteness of the inducers is, indeed, not a necessary requirement for the Ehrenstein illusion, given that illusory contours and surfaces arise just as well from radial arrangements of letters. This observation is consistent with earlier findings (Kennedy, 1976; Purghe & Coren, 1992) showing that illusory brightness can occur without the perceptual completion of the inducing elements and supports a bottom-up explanation of the Ehrenstein illusion in terms of neurophysiological mechanisms.

To provide insight into the potential physiological correlates of such these mechanisms, neurophysiologists (e.g. von der Heydt & Peterhans, 1989) have attempted to identify the neural interactions that would explain how the visual brain bridges gaps in physical structures. So-called *long-range interactions* between visual cortical neurons have been suggested as candidate mechanisms here (Kapadia *et al*, 1995; Dresp & Grossberg, 1995; Spillmann & Werner, 1996). Visual cortical neurons sensitive to the intensity and the direction of contrast (sometimes referred to as the *on-off* processing streams of the visual brain, e.g. Jung, 1964; Spillmann, 1994), selective to the orientation of inducing lines and integrating contour information from collinear lines and line-ends (e.g. Yu & Levi, 1997) on the basis of lateral interactions between cells across larger distances (e.g. see Spillmann & Werner, 1996; Dresp, 1999 and Polat, 1999 for reviews) have been considered. Such interactions are likely to generate neural signal exchanges which could explain how the perception of illusory figures is determined in the brain at the earliest stages of visual information processing (Proverbio & Zani, 2002; Spillmann & Ehrenstein, 2004). These assumptions are compatible with findings suggesting that illusory figures arise through bottom-up mechanisms that are put into place early in human visual development (e.g. Kavsek, 2002). Systematic and significant behavioural responses to illusory figures have been found not only in non-human primates but also in the independently evolved visual systems of

birds and insects (see Nieder, 2002, for a review). From the viewpoint of evolutionary neurobiology illusory contours reflect the activity of “dedicated” visual mechanisms that are critical for survival and therefore have to be fast and efficient (Dresp, 1997; Dresp & Spillmann, 2001).

## **Summary**

Visual perceptual illusions in general describe situations where a percept differs from the physical stimulus in a meaningful and often misleading way and an illusory percept as seen the Ehrenstein figure tells, indeed, a long story about the intricacy of our senses. It is often pointed out that our senses are deceiving – but are they really? One of the main scientific interest in the study of visual perceptual phenomena like the Ehrenstein illusion lies in the insight they allow into the sorting of sensory signals the brain has to accomplish to generate the resulting percept, “misleading” though it may seem. Deciding what is and what is not a perceptual illusion requires several stages of analysis, from a phenomenal description to the identification of physical variables which influence the phenomenal appearance, leading eventually to hypotheses about underlying brain mechanisms that can be put to the test experimentally. How this is to be approached will vary according to the theoretical standpoint of the scientist himself. The psychologist or evolutionary biologist may want to question to what purpose an illusory percept would have evolved at all, while the (psycho-) physicist or physiologist may focus on trying to understand how it is generated in the processes of brain development.

The attempt to understand both aspects of perceptual phenomena like the Ehrenstein illusion on the basis of principles of perceptual organization that take into account the physical constraints a stimulus imposes on the functioning of an organism which has evolved to perceive it was one of the core issues addressed by *Gestalt theory*, which is mentioned earlier here. The work by Walter Ehrenstein *senior* himself, which was carried on with much enthusiasm and success by his son Walter Ehrenstein *junior* subsequently, has laid the foundations of a large body of scientific investigations into this particular phenomenon, and others closely related ones.



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