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The phantom illusion

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Abstract

It is well known that visible luminance gradients may generate contrast effects. In this work we present a new paradoxical illusion in which the luminance range of gradual transitions has been reduced to make them invisible. By adopting the phenomenological method proposed by Kanizsa, we have found that unnoticeable luminance gradients still generate contrast effects. But, most interestingly, we have found that when their width is narrowed, rather than generating contrast effects on the surrounded surfaces, they generate an assimilation effect. Both high and low-level interpretations of this ‘‘phantom” illusion are critically evaluated.

Keywords:

Visual illusions, Lightness perception, Luminance gradients, Contrast and assimilation effects

1. Introduction

A spatial change in luminance within the retinal image can be produced by either an illumination change or by a surface reflectance change. Under many circumstances, we are able to correctly attribute the physical cause of the discontinuity. To do this, we benefit from all the information available in the retinal image. One important aspect of this information is the profile type of luminance change. When the profile of the luminance change in the retinal image is gradual, the luminance transition tends to appear as an illumination change; conversely, when the profile is sharp, the sharp edge tends to appear as a reflectance transition (Soranzo & Agostini, 2004; Soranzo, Galmonte, & Agostini, 2009).

Hering (1920/1964), for example, observed that a shadow covering a homogeneous surface appears as a dark stain if the gradual luminance transition at its edge is masked by a black ink. This demonstrates that a physical illumination edge may appear as a reflectance edge if its luminance profile is made to appear sharp rather than gradual.

Conversely, gradual luminance changes tend to be perceived as illumination edges even when they are physically generated by reflectance edges. Kennedy (1976) showed that a set of black dots grouped on a white background create the impression of radiating lines which fade towards the centre and generate the percept of a central glowing region (Fig. 1a).

Recently, a number of compelling visual illusions have been created through the use of gradients. In many cases, it is not known whether the illusion is produced because the observer interprets the gradient as arising from an illumination change. For example, Zavagno (1996, 1999) presented the illusion shown in Fig. 1b. The luminance of the central part of the cross is the same as that of the rest of the page, yet it appears quite different: a bright halo appears to cover about 3/4 of the area occupied by the cross.

Another illusory effect that is generated by luminance gradients was published by Gori and Stubbs (2006). Their display consists in a black background on which is placed a circular white spot; its boundaries are characterized by a luminance gradient that gives an impression of blur. The display produces the perception of a tunnel in depth that goes forward to the area having the highest luminance at the centre of the image (Fig. 1c).

Besides generating the perception of glares, blurs or halos, luminance gradients may also generate strong perceptual contrast effects. Agostini and Galmonte (1997, 1998, 2002) found that a grey region placed at the centre of an area filled by a linear achromatic gradient from black (outer part) to white (inner part) is perceived as being much darker than an identical middle grey region surrounded by the reversed gradient (Fig. 1d).

A different type of evidence that luminance gradients generate contrast effects has been provided by McCourt (1982). An inducing field containing a vertical sinewave luminance grating which surrounds a test field of similar spaceaverage luminance induces within the homogeneous test field a contrast effect that results in the appearance of a second sinewave grating of equal spatial frequency, but of opposite phase.

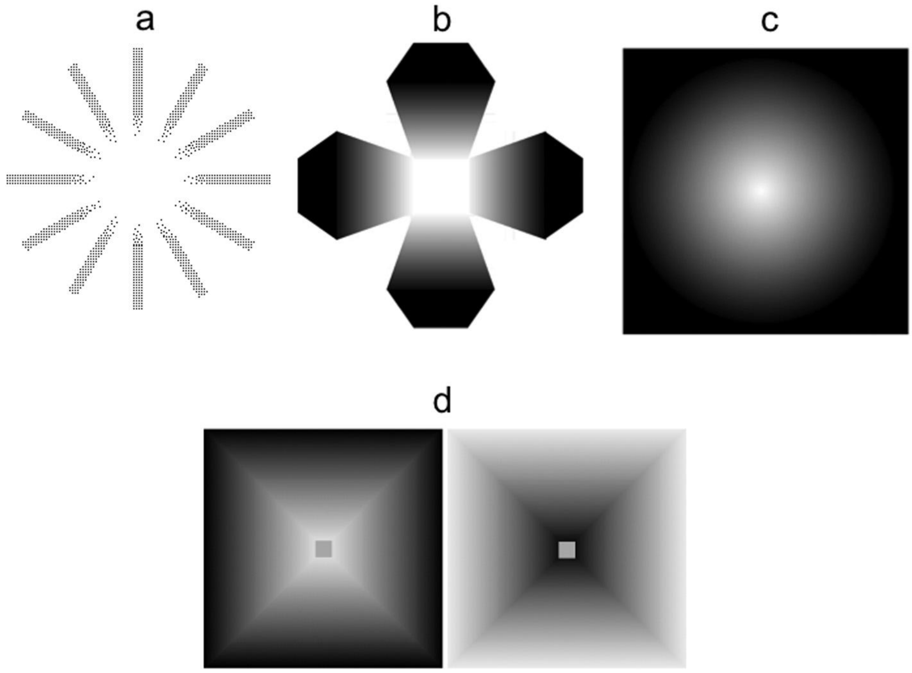

Fig. 1. Gradual luminance transition may generate the perception of glares, blurs or halos ((a) Kennedy's figure; (b) Zavagno's figure; (c) Gori & Stubbs' figure); luminance gradients may also generate contrast effects ((d) Agostini & Galmonte's figure).

Moulden and Kingdom (1991) demonstrated a low contrast version of this grating induction effect, in which a narrow homogeneous luminance stripe placed on a low contrast background sinusoidally modulated in luminance (but almost below threshold) appeared sinusoidally modulated but opposite in phase to the inducing grating. Their grating induction effect is particularly important for the purposes of the present paper because it demonstrates that luminance gradients may generate contrast effects even when their amplitude is reduced in order to be practically unnoticeable.

In summary, luminance gradients tend to appear as illumination edges, they may generate glares or halos, and they may generate strong contrast effects. Furthermore, these transitions do not need to be clearly visible: unnoticeable luminance gradients may still generate contrast effects. To underscore this point, consider a variant of the Agostini and Galmonte (2002) illusion where the steepness of the luminance gradients is reduced to be virtually unnoticeable (Fig. 2 top part). As the figure demonstrates, contrast effects persist even after the gradient's steepness has been reduced so as to make the gradient almost invisible. The two targets share the same luminance, but the one on the left appears darker. This contrast effect appears to be generated by the luminance surrounding the squares: the luminance surrounding the square to the left higher rather than that of the square itself; conversely, the luminance surrounding the square to the right is lower (refer to the luminance profile at the figure sides). This is compelling evidence that the luminance gradients do not need to be visible to generate contrast effects.

But what happens if the width of these luminance gradients is narrowed. Will they still generate contrast effects? Quite surprisingly, when the width of the invisible luminance gradients is narrowed, we find that they generate assimilation, rather than contrast: surfaces that are surrounded by a higher luminance appear lighter rather than equal surfaces that are surrounded by a darker luminance. Fig. 2 bottom part demonstrates this new illusion, which we call the phantom illusion because it is generated by imperceptible gradient inducers. The luminance surrounding the left target in Fig. 2 bottom part is the same as the luminance surrounding the left target in Fig. 2 top part. Similarly, the luminance surrounding the right target in Fig. 2 top part and in Fig. 2 bottom part is the same. However, the effect on targets lightness is the opposite.

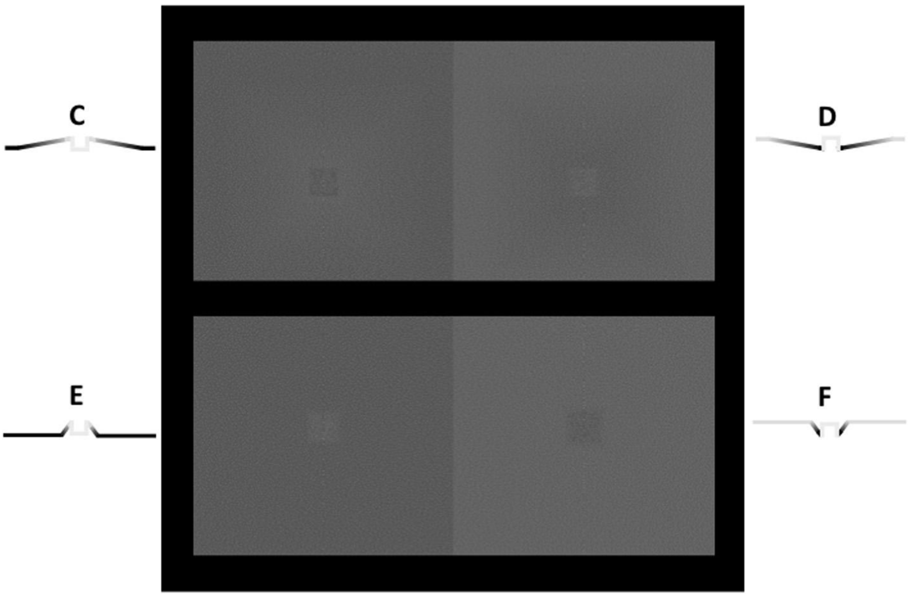

Fig. 2. The phantom illusion. In the top part of the figure unnoticeable luminance transitions generate contrast effects on the surrounded targets. In the bottom part of the figure everything is the same as in the top part of the figure, but the wideness of the luminance transition has been narrowed. In this case, unnoticeable luminance transitions generate assimilation effects on the surrounded targets. On the side of the displays are depicted the luminance profiles.

To test the hypothesis that the width of luminance gradients affects the lightness of the embedded surface, we ran an experiment aimed at collecting observational data from naïve participants.

2. Experiment

2.1. Methods

2.1.1. Observers

Twenty observers participated. All had normal or corrected to normal vision. They were naïve to the purpose of the experiment. The experiment was carried out according to our institution guidelines for ethical issues and in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki). Informed consent was obtained from participants.

2.1.2. Apparatus and stimuli

The stimuli were presented on a high definition Trinitron CRT monitor (1280 _ 1024 pixels) controlled by a PC. Luminance and chromaticity have been controlled. Fig. 3 depicts the luminance profiles of the stimuli.

There were three stimulus configurations. Each configuration was composed of three pairs of displays, arranged vertically and presented simultaneously to the observers. Each display included one background and one target. The display pairs were as follows: luminances were 22.4 and 24.6 cd/m2 respectively. At each background centre there was a target subtending 0.28L and whose luminance was 23.5 cd/m2.

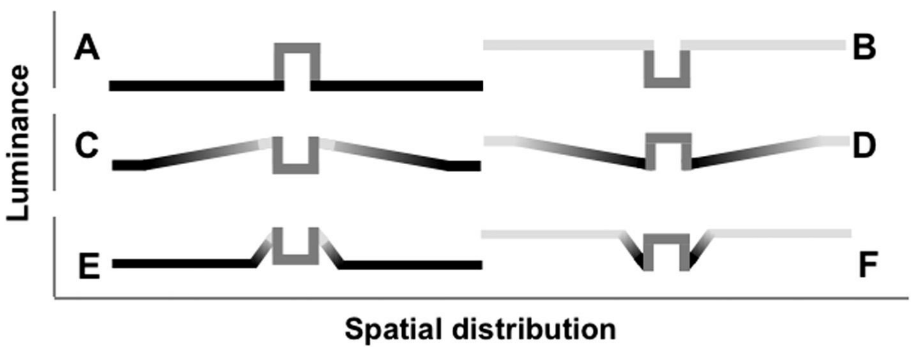

Fig. 3. Luminance profiles of the experimental stimuli.

Display pair CD. The display pair CD included the square shaped backgrounds C and D subtending 6.4 deg each, and each filled by a linear achromatic luminance gradient. The gradient filling background C ranged from 22.4 to 24.6 cd/m2 towards the centre. The gradient filling the background D had the opposite polarity: it ranged from 24.6 to 22.4 cd/m2 towards the centre. At the backgrounds centre there were two targets which were the same as for the displays AB

Display pair EF. The display pair EF was like pair CD, except that the luminance gradient surrounding the targets had width 0.07L instead of 6.45L. Hence the gradient was steeper. The three stimulus configurations were defined as follows:

Configuration 1: Pair AB was presented atop Pair CD (Fig. 4);

Configuration 2: Pair AB was presented atop Pair EF (Fig. 5);

Configuration 3: Pair CD was presented atop Pair EF (Fig. 6).

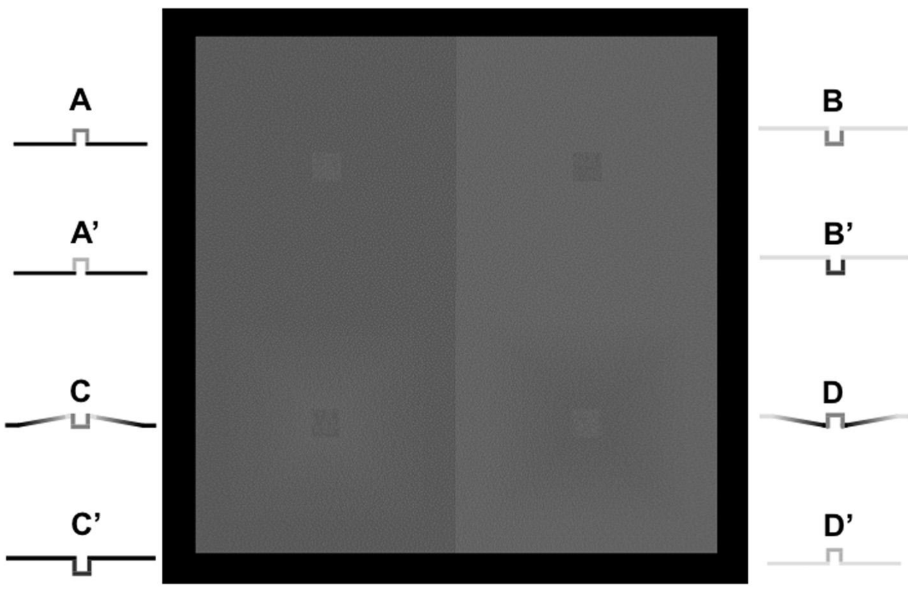

Fig. 4. Configuration 1, display pairs AB atop display pair CD. On the side of the displays are depicted the luminance profiles. Profiles A', B', C', and D' epitomize the perceptual phenomenal outcome as reported by the observers.

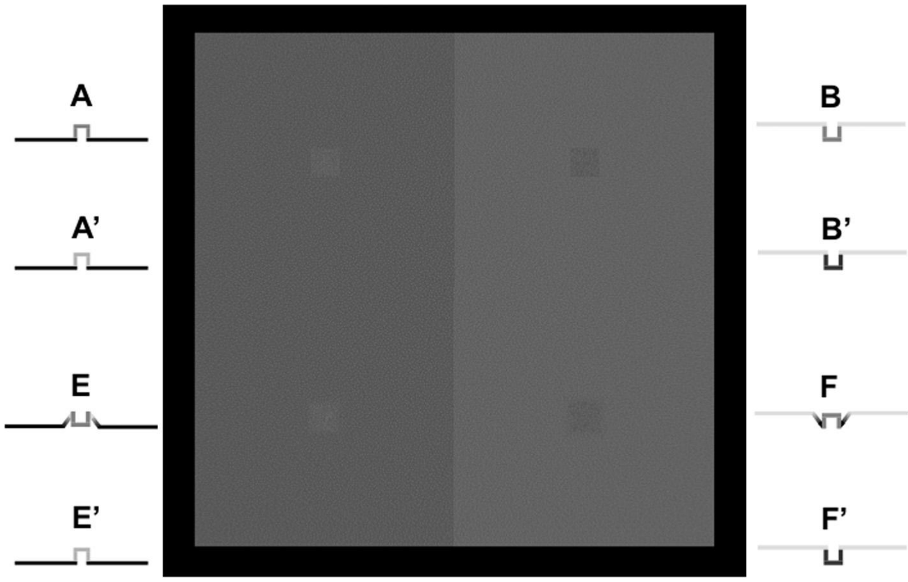

Fig. 5. Configuration 2, display pairs AB atop display pair EF. On the side of the displays are depicted the luminance profiles. Profiles A', B', E', and F' epitomize the perceptual phenomenal outcome as reported by the observers.

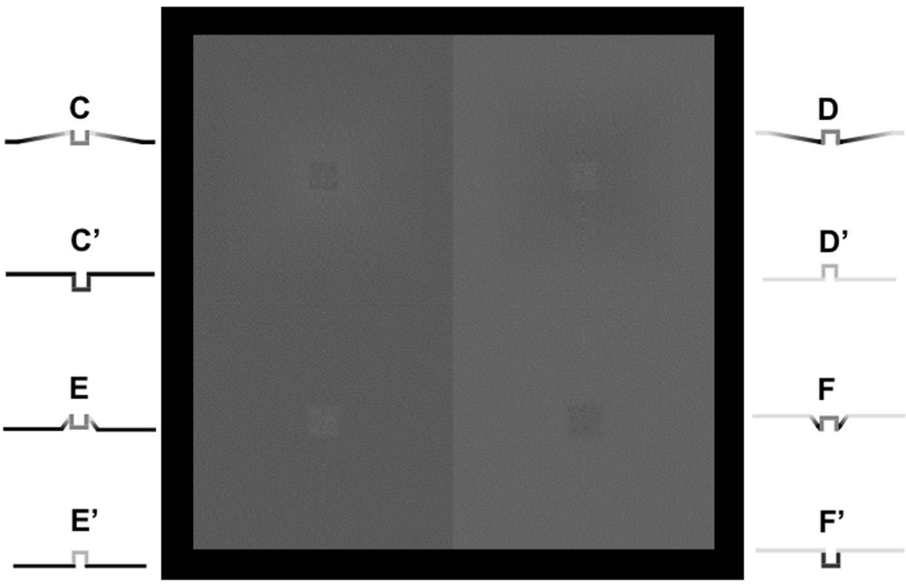

Fig. 6. Configuration 3, display pairs CD atop display pair EF. On the side of the displays are depicted the luminance profiles. Profiles C', D', E', and F' epitomize the perceptual phenomenal outcome as reported by the

observers.

2.2. Procedure

To test the hypothesis that the width (or steepness) of a surrounding luminance gradient can influence the lightness that it induces in a fixed target, we used the phenomenological procedure proposed by Kanizsa (1954). Each observer was first asked to describe the experimental configuration and then the experimenter pointed to one stimulus and the observer was asked to choose among the others the most similar in lightness. Observers were tested individually. They were seated 50 cm away from the computer screen, in a dark experimental room. The stimuli were viewed binocularly and free viewing was allowed.

3. Results and discussion

3.1. Configuration 1

When observers were presented with Configuration 1 (display pair AB atop display pair CD; Fig. 4), they described the visual scene as comprising four small grey squares placed on two adjacent rectangles. The rectangle on the left was reported to be darker rather than the rectangle on the right. Importantly, none of the observers noticed the gradual luminance gradient. Background C was seen as an elongation of Background A and, similarly, Background D was seen as an elongation of Background B. If observers did not report it spontaneously, the experimenter pointed to each one of the four targets and asked each observer to choose among the others the most similar in lightness. All the observers reported that the target on A was most similar to the target on D, and the target on B as being similar to the target on C. Thus, the backgrounds—which were physically different—were perceived to be the same; whereas, the four targets that were physically the same were perceived to be different.

The experimental results clearly indicate that luminance gradients do not need to be visible in order to influence the lightness of embedded surfaces. In light of this fact, the direction of the induction effect produced by pair CD is not surprising. This effect is just an invisible gradient version of the effect demonstrated earlier by Agostini and Galmonte (1997, 2002).

3.2. Configuration 2

When observers were presented with Configuration 2 (display pair AB atop display pair EF; Fig. 5), they described the visual scene in a similar way as for Configuration 1. Background E was seen as an elongation of Background A and Background F was seen as an elongation of Background B. If observers did not report it spontaneously, the experimenter pointed to each one of the four targets and the observers were asked to choose among the others the most similar in lightness. All the observers reported that the target on A was most similar to the target on E and the target on B was most similar to the target on F. None of the observers noticed the gradual luminance gradient. Like the results of the experiment based on pair CD, the results of the experiments with pair EF demonstrate that invisible gradients can affect target lightness in the same way that visible induc ers do. However, in the case of pair EF, the induced effect is one of lightness assimilation, rather than contrast. Our results suggest that the critical factor determining whether the gradient induction effect is one of contrast or assimilation is either the total width, or the steepness, of the surrounding gradient.

3.3. Configuration 3

When observers were presented with Configuration 3 (display pair CD atop display pair EF; Fig. 6), they described the visual scene in the same way as for Configuration 1 and 2. Again, none of the observers noticed the luminance gradients and background E was seen as an elongation of Background C, while Background F was seen as an elongation of Background D. If observers did not report it spontaneously, the experimenter pointed to each one of the four targets and they were asked to choose among the others the most similar in lightness. All of the observers reported that the target in display F was more similar to the target in display C than the target in display D and that the target in display E was more similar to the target in display D. Again, the backgrounds, which were physically different, were perceived to be the same, while the four targets that were physically the same were perceived to be different, indicating the existence of a paradoxical lightness effect.

Like the results of the experiment with Configuration 2, the results obtained with Configuration 3 demonstrate that a luminance gradient can influence the perceived lightness of an embedded target, even when the gradient itself is imperceptible. However, the lightness induction effects observed in the two experiments are opposite in direction: when the invisible gradient was more gradual, and had a wider spatial extent, in Configuration 2, the lightness induction effect had the sign of contrast; whereas, the more narrow, steeper gradient in Configuration 3 produced an induction effect having the sign of assimilation, even though the luminance range covered by the luminance gradient was the same in the two cases. This suggests that either the gradient width, or steepness, or both, is a key factor in determining the sign of the lightness induction produced.

4. Conclusions

Compelling visual illusions have been generated by controlling luminance gradients, both here and in previous work. It has previously been shown that gradients can generate the appearance of glow, halo or blur. Furthermore, it has been demonstrated that luminance gradients may generate strong contrast effects. Moreover, Moulden and Kingdom (1991) have shown that luminance gradients do not need to be clearly visible to generate contrast.

In the present work, we manipulated the width of invisible luminance gradients and obtained a compelling and paradoxical lightness illusion (Fig. 2). We found that, whereas wide, invisible luminance gradients generate contrast effects in a target that they surround, narrow, invisible luminance gradients generate assimilation effects, even when the wide and narrow gradients span the same total luminance range.

It might be thought that the assimilation effect observed with the narrow gradient (display pair EF) is due not to lightness assimilation from the gradient itself, but rather to contrast with respect to remote backgrounds on the two sides of the display. The latter differed in proximity to the target in our stimulus pairs, and therefore possibly in the strengths of the contrast effects that they induced in the target. In our narrow gradient experiment, the outer background was only 0.07L from the target; so one might argue that the outer background could have had a larger effect on the disk appearance than the local surround, even if the influence of the remote background was smaller than that of the gradient due to its increased distance from the target. However, a number of other results in the literature suggest that the width of the local surround is an important factor in determining whether assimilation or contrast will be produced, even when the luminance of the remote background is held constant. For example, Rudd (2010) surrounded a dark disk with lighter rings of different widths and varied the ring luminance. When the ring was sufficiently wide, the induced lightness always had the sign of contrast visàvis the ring luminance. But assimilation was observed with narrower rings. In fact, greater amounts of assimilation were obtained as the ring width was decreased, down to a width of 0.12L (Fig. 7), which is nearly the same width as that of the narrow gradient used in the present study. In the Rudd (2010) study, the disks and rings were always viewed against the same white background, so the remote background luminance could not have been the determining factor for producing assimilation. Rudd's quantitative results are consistent with a number of other qualitative results demonstrating that assimilation occurs mainly with narrow surrounds (Helson, 1963; Shevell, 2003; von Bezold, 1876). However, the results demonstrated in the present paper are unique in that the assimilation effects are produced by a narrow surround consisting of luminance gradients, rather than a surrounding field of homogeneous luminance; and, furthermore, even when these gradients are invisible. Although the fact that the local surround width appears to be the critical factor in determining whether assimilation will occur for both gradients and homogeneous surrounds, this still does not explain why assimilation occurs in the first place. Furthermore, there may be something special about the contrast and assimilation effects produced by gradients. In the following sections, we outline some possible low and high-level explanations of our effects, discussing both the pros and cons of the various theories.

4.1. The phantom illusion: high-level interpretations

According to one high-level interpretation, luminance gradients are perceived as illumination cues (Agostini and Galmonte, 1997, 2002; Soranzo et al., 2009). Depending on the gradient polarity, a surface seen in the presence of a gradient will appear either on a lighted field (Background D, Fig. 4), or in a cast shadow (Background C, Fig. 4). This explanation can account for contrast effect seen in the original version of the phantom illusion—the one with the wide gradient—as an effect of discounting the illuminant (Helmholtz, 1866/1924), but it cannot account for the assimilation effects observed here with invisible narrower gradients. One possible explanation of this dichotomy is that shallow gradients in the retinal image are likely to be interpreted as resulting from illumination variation, while steep gradients are more likely to be interpreted as a resulting from reflectance variation (Gilchrist, 2006; Land & McCann, 1971).

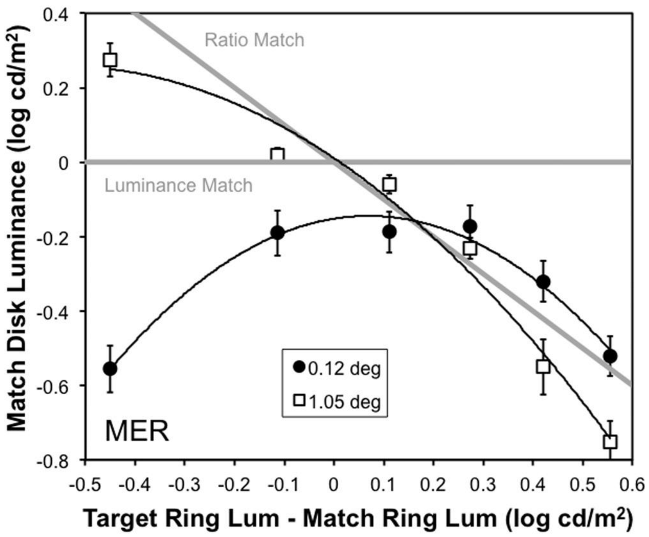

Fig. 7. Replot of data from Rudd (2010, Experiment 1) demonstrating lightness assimilation in a diskring display for narrow rings (rings). The disk was a luminance decrement with respect to the ring, and the ring a luminance decrement with respect to a highest luminance white background field. The observer adjusted the luminance of a match disk (0.35L diam.) surrounded by a ring of fixed intensity (0.7 log cd/m2) to match target disk having the same diameter as the match disk, and surrounded a ring of the same width, but variable luminance, both viewed against the same white background as the match configuration. The experiment was performed with equal match and target ring widths of either 0.12, 0.58, or 1.05L. For the 1.05L ring, the lightness matches approached a ratio match, indicating a contrast induction effect from the ring. For the two narrower rings, lightness assimilation was observed when the target ring luminance was lower than that of the match ring. This is demonstrated in the above data plot by a tendency for the match settings (which measure the target lightness) to decrease as the difference between the target and match luminances (xaxis) becomes more negative. The data from the two ring conditions has been fit with a parabolic regression model (solid lines), which was shown by Rudd (2010) explain 96% of the variance in match settings from the three ring conditions and two experimental subjects. The parabolic law is explained by a neural model presented in Rudd (2010) and summarized briefly in the Section 3 of the present paper.

An alternative high-level interpretation that can account for both the contrast and assimilation effects, is based on the gestalt principle of perceptual belongingness: that is, the grouping of a set of apparent elements into a perceived whole (Wertheimer, 1923/1939). King (1988) holds that when belongingness produces a single perceptual unit, assimilation will be favoured over contrast. On the other hand, when two perceptual units are formed, contrast is more likely to occur. In other words, when belongingness involves independent perceptual units, it generates contrast; when belongingness creates a single perceptual unit, then assimilation occurs among the subunits of the whole (Soranzo, Galmonte, & Agostini, 2010). Consonant with this idea, it might be hypothesized that in the display pair E and F (Fig. 5), the narrow unnoticeable transitions constitute a single perceptual unit with the targets and therefore, assimilation occurs. As regards the display pair C and D (Fig. 4), the wide unnoticeable transitions tend to group with the background, hence generating contrast.

4.2. High-level interpretations: objections and replies

A problem with the first high-level interpretation—the one based on illumination cues—is how to interpret the contrast effect obtained with the display pair CD, in which the luminance gradients were barely visible. At first sight, it seems therefore unlikely that these gradients were interpreted as a strong illumination cue. However, Keil (2007) suggested that luminance gradients and illumination are processed by one and the same perceptual mechanism, and classified as perceptual features. Perceptual features require few attentional resources to be processed (Joseph, Chun, & Nakayama, 1997). Hence, it might be argued that luminance gradients can be processed as illumination cues without requiring the attentional resources required to achieve awareness. In fact, this is simply a contemporary restatement of Helmholtz's famous assertion that lightness perception is achieved by unconscious inferences regarding the nature of the illumination (Helmholtz, 1866/1924). Moreover, recent experimental evidence from priming studies directly supports the claim that illumination cues can be both perceptually processed, and discounted, even when the stimulus is made invisible by a subsequently presented metacontrast mask (Kentridge, Norman, Akins, & Heywood, 2015). We therefore conclude that the validity of a high-level interpretation of our results based on illumination cues does not hinge critically on whether the luminance gradients in our study were actually invisible, or merely ‘‘almost” invisible.

A problem with the second high-level interpretation—the interpretation based on belongingness—is that it the contrast effect that is seen with wide, virtually invisible gradients is perceptually paradoxical, being the target perceived as, respectively, darker/lighter when it is placed on a apparently uniform dark/light background, since such gradients would also be expected to perceptually group with the background, due to their invisibility. A second problem with the high-level interpretation based on belongingness is that the belongingness concept is difficult to operationalize. Although it has been used successfully to explain more complex perceptual phenomena, it is founded on high-level cognitive constructs that lack a clear connection to underlying anatomical and physiological processes at the present time. However, at least one promising research (Biederlack et al., 2006) has attempted to link feature binding (a concept that can be considered quite similar to that of belongingness) in brightness phenomena to synchronization processes in the brain.

4.3. The phantom illusion: low-level interpretations

The contrast effect observed with the wide, shallow gradients might alternatively be explained on the basis of low-level contrast mechanisms, such as those assumed in the DOG (Kingdom, McCourt, & Blakeslee, 1997) and ODOG (Blakeslee & McCourt, 1999) brightness models. These models assume that lightness is encoded by banks of narrowband spatial filters, which are ‘‘generally understood to be retinal and cortical neurons, whose receptive fields perform bandpass filtering operations on the distributions of luminance in scenes” (Kingdom et al., 1997, p. 1039). The kernels of the bandpass filters in the DOG model have a centre-surround organization, such that the presence of luminance in the surround will inhibits the centre response to a target. The ODOG model is similar to the DOG model, except that it substitutes oriented spatial filters for filters with centre-surround receptive field organization.

Blakeslee and McCourt (1997) proposed a version of the DOG model that included very low spatial frequencytuned filters and showed that this model could explain the lightness response to many stimuli. The low spatial frequency filters in their model could likely also account for the contrast effects seen in our experiments with wide, shallow gradients, due to the centre surround structure of the underlying filters.

Either the DOG or ODOG model might also be able to account for the assimilation effects seen in our experiments with narrow, steep gradients because such assimilation effects would arise from local averaging of luminance within large receptive fields centres of the lowest frequencytuned model filters. Similar neuronal explanations of assimilation have previously been proposed by several authors (DeValois & DeValois, 1975; Helson, 1964; Hurvich & Jameson, 1966; Hurvich & Jameson, 1974; Jameson & Hurvich, 1975). Another factor that may influence assimilation in these models is contrast normalization that occurs across spatial filters tuned to different peak frequencies. Contrast normalization acts to even out the activities of the model filters. Blakeslee and McCourt (1999, 2004) simulated the response of an ODOG model that included contrast normalization to several visual displays and showed that the model is capable of explaining a host of lightness induction effects, including the lightness assimilation seen in White's effect (White, 1979, 1981).

A different neural model of lightness computation, based on the principle of edge integration, was proposed by Rudd (2010) to account for the assimilation effects that he observed in his experiments with diskring displays (Fig. 7). The edge integration model assumes that the lightness of the target disk in a diskring display is computed from a weighted sum of the directed luminance steps evaluated at the inner and outer edges of the annular surround (see also Reid & Shapley, 1988; Shapley & Reid, 1985), The directed luminance step at the inner edge of the ring (i.e. the disk-ring edge) exerts a contrast effect on the disk lightness, while the directed luminance step at the remote outer edge of the ring (the ring background-edge) exerts an additional effect on the disk lightness that can have the sign of contrast or assimilation, depending on the direction of the remote luminance step (for the stimulus in Fig. 7, the luminance step in the direction of the target is negative sign of the induction effect from this edge is one of contrast).

When the outer edge instead produces an assimilation effect, the magnitude of the assimilation effects tends to be weaker than the contrast effect produced by the diskring edge because the outer ring edge is further from the target. Thus, in the absence of some additional mechanism beyond edge integration alone, the total influence of the surrounding context on the disk lightness will always have the sign of contrast, even when the luminance step at the outer edge of the ring is positive and the effect of this edge is one of assimilation.

To account for the fact lightness assimilation is sometimes the dominant effect from the surround, Rudd modified the edge integration model by assuming the existence of a contrast gain control that acts between cortical neurons with oriented receptive fields that respond to the inner and outer edges of the ring at two stages of a hierarchical network. This contrast gain control can act to either suppress or amplify an edge response at the second neural stage on the basis of the magnitude of the neural response to the other edge at the first stage. The magnitude of the suppression or amplification at the second stage increases with size of the luminance step at the opposite edge at the first stage. In fitting this model to data from several diskring experiments, Rudd found that the contrast gain control directed from neurons responding to the outer ring edge at the first neural stage to neurons responding to the inner ring edge at the second stage had to be suppressive, while the contrast gain control directed from the inner ring edge at the first stage to the outer ring edge at the second stage had to be amplifying.

When these contrast gain control mechanisms are added to the basic edge integration model, the edge integration model produces an overall assimilation effect from the ring onto the disk under conditions in which the contrast of the outer edge is high and the contrast of the inner edge is low, consistent with data (see parametric modeling of lightness matching data in

Rudd, 2010). When the opposite conditions hold, the ring exerts an overall contrast effect onto the disk.

Rudd (2010, 2013) proposed that edge integration is carried out at the cortical level by spatially integrating at a higher cortical stage (possibly V4) the responses of V1 or V2 neurons whose receptive fields are tuned to oriented contrast. Like the evensymmetric receptive fields in the ODOG model, the oddsymmetric receptive fields in the edge integration model are assumed to exist at multiple spatial scales and thus to be sensitive to a variety of spatial frequencies. They would therefore be expected to respond to both hard edges and gradients exhibiting different degrees of gradualness. For an oriented receptive field of a given scale and contrast polarity, the steepness of the gradient would modulate the neural response to the gradient in a manner that is similar to the contrast the outer ring edge in a disk-ring display. A steep, narrow gradient would act like a high contrast outer ring edge in excited the V1 oriented contrast neurons; and a shallow, wide gradient would act like a low contrast outer ring edge.

Fig. 8 shows the results of a 1D simulation of this model in which the response of a V1 neuron to the target edge was assumed to scale linearly with the luminance step (in log units) at the target edge and the neural response at every location in the gradient was assumed to scale linearly with the gradient slope (in log units). As can be seen from the figure, the model correctly accounts for the basic qualitative properties of the phantom illusion. It produces an overall lightness response to a decremental (incremental) target that is paradoxically higher than its lightness response to an incremental (decremental) target when the target is surrounded by a steep, narrow gradient. But its lightness response to a decremental (incremental) target that is veridically lower than its lightness response to an incremental (decremental) target when the target is surrounded by a shallow, wide gradient. Although it may seem surprising that the model can make a an increment look like a decrement, and vice versa, it is a consequence of the central idea of the model that lightness is the result of a cortical process that integrates luminance steps across a substantial portion of the visual field in combination with relatively low-level mechanisms involving contrast gain control.

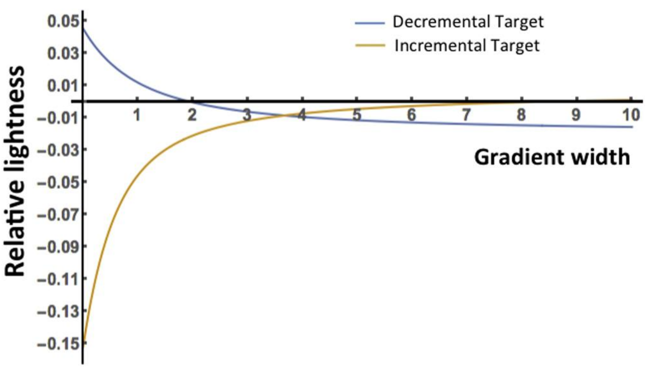

Fig. 8. 1D computer simulation of the phantom illusion based on Rudd's edge integration model. Contrast gain control was assumed to occur between pairs of Stage 1 and Stage 2 oriented contrastdetecting neurons

(assumed to be located in areas V1 or V2 of visual cortex) in a manner that decays as an exponential function of distance between the Stage 1 and Stage 2 neuronal receptive field centres (in retinal coordinates). Outwardlydirected gain control was always amplifying (i.e. facilitatory) and inwardlydirected gain control was always inhibitory. Lightness was modeled by spatially integrating—in the direction of the target centre—the outputs of the Stage 2 neurons, weighted by spatial weighting coefficients that fell off exponentially with distance from the target centre. The gains of the Stage 1 neurons that respond to target edges or gradients whose light sides pointed inward, towards the target, were assumed to be 1/3 as large as the gains of the Stage 1 neurons responding to target edges or gradients whose dark sides pointed inward, towards the target, in order to account for documented quantitative asymmetries in the strengths of lightness and darkness induction (Rudd, 2013; Rudd, 2014). The model reproduces the basic phenomenological properties of the phantom illusion, according to which incremental targets appear lighter than decremental targets when the surrounding gradient is shallow and wide; while decrements appear paradoxically lighter than incremental targets when the surrounding gradient is steep and narrow.

Although the ODOG and edge integration models differ in significant ways—for example, the edge integration model requires a neural stage that integrates individual filter outputs across space—together they suggest that there are multiple ways by which low-level neural mechanisms could produce the contrast and assimilation effects seen in our experiments.

4.4. Low-level interpretations: objections and replies

One potential problem with the low-level interpretations is that the behavior of the various models depends critically on the model parameters, including the sizes of the various filters and the strengths of their interactions. An individual spatial filter in the DOG model would produce assimilation when the target and inducing field both fall within the centre region of the filter's centre-surround receptive field, and contrast when the target falls with the centre and the inducer within the surround. Assimilation might be produced at some filter scales and contrast at others. Adding contrast normalization to the model would further modify these effects. This raises the question of whether such models are able to produce any arbitrary direction and magnitude of lightness induction effect when the model parameters are free to vary. In simulations of the DOG and ODOG models, the parameters were carefully chosen to produce the desired effects and have not been kept constant across simulations of different lightness phenomena. The support for the models would be stronger if it could be shown that a single version of such a model could accounts for a large array of lightness phenomena with a fixed set of parameters.

Similarly, although Rudd (2013) has recently introduced a version of his edge integration model in which many parameters are fixed and which applies to the staircaseGelb paradigm (Gilchrist et al., 1999) as well as diskring experiments, not all of the parameters of his model have been fixed across studies. Furthermore, the edge integration model has not been applied to the large array of lightness that the DOG and ODOG models have been applied to. Thus, like the DOG and ODOG models, the ability of the edge integration model to give a comprehensive account of a large body of lightness phenomena with a single fully parameterized model has not yet been demonstrated.

Probably more importantly, neither the DOG/ODOG formalism, nor the edge integration formalism, includes a mechanism to perform edge classification, which is required in order to exclude illumination edges from computations intended to encode perceived reflectance. Rudd (2010) demonstrated that instructions that biased an observer to interpret a sharp edge as the result of either a spatial reflectance or illumination transition had the effects of changing the weights given to an edge in the image. As noted in the Introduction, the observers tend naturally to interpret luminance transitions in the image as reflectance or illumination edges, depending on the nature of their luminance profiles, a factor that has been ignored in the simulation presented above of the phantom illusion with Rudd's edge integration model presented. Clearly, edge classification is required to give a full account of lightness perception and, if an edge classification mechanism were to be added to either of these classes of low-level models, then that would introduce the likelihood that high-level factors—including assumptions about the nature of the illuminant—would also play a role in the interpretation of the phenomena studied here. Furthermore, Rudd (2013) has argued that perceptual organization plays a role in the determination of edge integration paths, even for the apparently simple case of the diskring stimulus. Finally, the sign of contrast gain control in his edge integration model is defined relative to objectcentred coordinates (negative for gain modulations directed towards the target and positive for gain modulations directed away from the target. So, Rudd's model describes a perceptual computation that is perhaps best described as 'midlevel' rather than 'low-level.'

In fact, in its most recent formulation (Rudd, 2014), the edge integration model has been extended to include the assumption of 'high-level ' neural image classification mechanisms that distinguish between perceived reflectance and illumination cues in the retinal image and suppress, through topdown feedback to early visual cortex (area V1 and/or V2), the responses of low-level oriented spatial filters that respond to illumination edges in the retinal image. As a result of this topdown inhibition, only reflectance edges enter into the edge integration computation, which is assumed to occur in a feedforward manner within the ventral cortical stream from early visual cortex and area V4 (see Rudd, 2010, 2013, 2014 for details). The contrast gain control stage of the neural edge integration model acts on the outputs of low-level oriented filters whose neural gains have already been adjusted by this topdown gain control to exclude, or at least attenuate, illumination 'edges.' So, if gradual changes in luminance in the retinal image are interpreted by the observer to be illumination gradients, their effects will be neurally attenuated by topdown feedback prior to the gain control stage. When this occurs, gradients will neither exert gain control on the target edges, nor vice versa; and the gradients will not contribute to the edge integration computational of lightness.

In what follows, we formalize these ideas in the context of our computational model of the Phantom Illusion. Specifically, we show that adding such topdown inhibition of shallow gradients to the edge integration model does not impair the model's ability to account for the illusion. We have already shown (in Fig. 8) that the edge integration model can explain the illusion when the shallow gradient is interpreted as being due to reflectance variation and thus is input to the edge integration model. We now demonstrate that the local contrast between the target and its immediate surround will dominate the output of the edge integration computation when the target is surrounded by a shallow gradient, even if he shallow gradient is interpreted as an illumination gradient and thus its effects are neurally attenuated by topdown feedback prior to the gain control and edge integration stages of the model. Neural responses to steep gradients are not attenuated because steep gradients are likely to be classified as reflectance edges, so steep gradients continue to influence lightness in the same way that they did in the simulation used to produce Fig. 8.

To instantiate this model in a computer simulation, we decided not assume that the observer sets a sharp perceptual threshold between classifying shallow gradients as illumination gradients and steep gradients as reflectance edges. We instead assumed that the topdown gain applied to the outputs of the oriented spatial filters in the edge integration model rolls off exponentially at low spatial frequencies. This will, in turn, have the effect of attenuating the neural response to shallow gradients and seems like a more neurally plausible hypothesis. To incorporate this idea into the computational model, the edge response at each location within the gradient—which, as in the simulation leading to Fig. 8, is assumed to be proportional to the slope—was multiplied by the gain factor.

$$g(s) = ke^{-s_0/s},$$

where s is the gradient slope, k and s0 are model constants. Eq. (1) implies that the gain applied to the low-level oriented filter outputs falls off exponentially as an inverse function of the gradient slope. Thus, the shallower the slope, the less influence the gradient will have on either the gain control stage or the edge integration stage of the model. Again, the 'high-level ,' or cognitive, interpretation of this gain rolloff is that some cortical edge classification process is less likely to classify a luminance gradient in the retinal image results as resulting from reflectance change, and more likely to assume that it results from an illumination change, as the slope of the gradient decreases; thus the effects of shallow slopes are eliminated—or at least attenuated—prior to the neural edge integration computation of lightness, consistent with the neural model described by Rudd (2010, 2013, 2014).

In Fig. 9, we present the results of a simulation in which we have applied the gain factor (1) to all oriented filter outputs, prior to inputting these outputs to contrast gain control stage of the model. Except for the inclusion of this gain factor, the model used to produce the results shown in Fig. 9 was otherwise identical to the one used to produce Fig. 8 (including the same model parameters). Like the edge integration model that was used to produce Fig. 8, the model with low spatial frequency roll off reproduces the basic qualitative properties of the Phantom Illusion: contrast for wide, shallow gradients and assimilation for narrow, steep gradients. However, the switch from assimilation to contrast occurs at a narrower gradient width in which the neural gain rolls off for shallow gradients according to Eq. (1).

Although we have thus far given a topdown gain control interpretation to the gain rolloff expressed by Eq. (1), it is important to note that the gain rolloff could alternatively be achieved by a low-level (bottomup) neural adaptation mechanism. At any given retinal location, visual cortex contains a set of spatial filters tuned to different spatial frequencies. Low spatial frequency filters are more sensitive to shallow gradients and high spatial frequency filters to steep gradients. In natural vision, an observer's eyes are always in motion. Even when we fixate on a detail of scene, our eyes will constantly make the small random microsaccades, causing the edges and gradients in the scene to randomly jitter across the receptive fields of the oriented filters in visual cortex. The responses of cortical neurons whose retinal inputs fail to change substantially over time tend to habituate and this is thought to be responsible for the perceptual fading of stabilized images (Riggs, Ratliff, Cornsweet, & Cornsweet, 1953; Troxler, 1804), through adaptation of quasistabilized retinal images, or by topdown feedback from neural edge classification mechanisms that suppress the activities of oriented spatial filters that are judged to be responding to spatial variation in illumination within the retinal image which occurs gradually, over a period of seconds. During periods of fixation accompanied by microsaccades, the neural habituation that produces perceptual fading is more likely to fatigue the responses of the low spatial frequency filters—which preferentially process shallow gradients—because these filters see less change in their input for a fixed amount of random jitter.

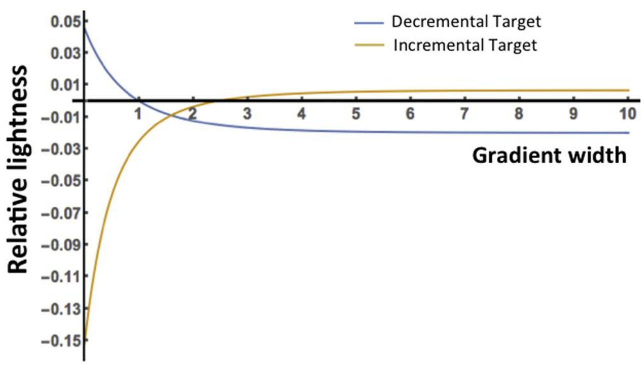

Fig. 9. 1D simulation of the phantom illusion based on an edge integration model in which the neural effects of shallow gradients are attenuated in the early stages of cortical processing, so that only reflectance edges only are passed on the subsequent neural stages associated with contrast gain control and edge integration. For concreteness, the neural gain applied to the outputs of local oriented filters was assumed here to fall off inversely

with the gradient slope, according to Eq. (1) in the main text. We set k = 1 (for simplicity) and s0 = 0.02. This choice of s0 implies that the neural gain applied to oriented filter response at locations with a narrow gradient of width 0.7L is 0.50 and the gain applied to oriented filter responses with a wide gradient of width 6.45L is 0.0016. The gain applied to filters responding to the target edge was 1.0, as in the model without low spatial frequency attenuation (simulated in Fig. 8). The two models are otherwise identical. Both models reproduce the main phenomenological characteristics of the phantom illusion: lightness assimilation in the case of narrow gradients and lightness contrast in the case of wide gradients. In the text, we discuss two possible mechanisms for producing the attenuation of neural signals based on shallow gradients. Both assume that the attenuation is accomplished by reducing the neural gain of low spatial frequency mechanisms in early visual cortex, either.

For this reason, the model that includes the gain rolloff expressed by Eq. (1) could alternatively be interpreted as an neural edge integration model in which there is no high-level edge classification and topdown feedback, but instead uses this low-level adaptation mechanism to attenuate the neural response to shallow illumination gradients. We think that both possible interpretations are plausible. However, even if gradients are attenuated by low-level adaptation, a high-level classification explanation is still required to explain results reported by Rudd (2010) that the perceptual weights given to sharp edges of fixed contrast in the process of edge integration can be altered by instructions to the observer to classify of the edge as either a reflectance or an illumination edge. So we are once again led to conclude that both low-level and high-level interpretations of the Phantom Illusion remain plausible, even in the context of our formal neural model. Further research will be required in order to fully flesh out and experimentally test these ideas.

In summary, we have shown here, using the phenomenological method of Kanizsa, the existence of an exciting new visual illusion—the phantom illusion—in which the width of an invisible luminance gradient determines the lightness of a target that it surrounds. In this illusion, wide invisible gradients generate contrast effects, while narrow invisible gradients generate assimilation effects. In principle, these effects could be accounted for by both high and low-level interpretations. Many theoretical approaches have been proposed to explain lightness, as surveyed in a recent review article by Kingdom (2011). We have made no attempt to address them all here. However, some notable approaches that we have not discussed—including Gilchrist's Anchoring theory, Land's Retinex theory, and Grossberg's fillingin models—have been critiqued by Rudd (2010, 2013, 2014) in the context of his arguments in favor of the edge integration approach. These critiques remain relevant in the current context. The Phantom Illusion is new and theoretically challenging—it makes increments appear and decrements and vice versa!—and we feel that is best to let theorists with alternative viewpoints defend their own theoretical approaches to explaining it, rather than trying to second guess them. In any case, we believe that further research of both a theoretical and an experimental nature will be required to decide whether the Phantom Illusion is best explained by low-level, or high-level interpretations, or some combination of the two.

References

Agostini, T., & Galmonte, A. (1997). Luminance gradients, perceived illumination, and lightness perception. Review of Psychology, 4, 3–6.

Agostini, T., & Galmonte, A. (1998). A luminance gradient paradox. Investigative Ophthalmology and Visual Science Supplement, 39(4), S158.

Agostini, T., & Galmonte, A. (2002). A new effect of luminance gradient on achromatic simultaneous contrast. Psychonomic Bulletin & Review, 9(2), 264–269.

Biederlack, J., CasteloBranco, M., Neuenschwander, S., Wheeler, D. W., Singer, W., & Nikolic´, D. (2006). Brightness induction: Rate enhancement and neuronal synchronization as complementary codes. Neuron, 52, 1073–1083.

Blakeslee, B., & Mc Court, M. E. (2004). A unified model of brightness contrast and assimilation incorporating oriented multiscale spatial filtering and contrast normalization. Vision Research, 44(21), 2483–2503.

Blakeslee, B., & McCourt, M. E. (1999). A multiscale spatial filtering account of the White effect, simultaneous brightness contrast and grating induction. Vision Research, 39, 4361–4377.

Blakeslee, B., & McCourt, M. E. (1997). Similar mechanisms underlie simultaneous brightness contrast and grating induction. Vision Research, 37, 2849–2869.

DeValois, R. L., & DeValois, K. K. (1975). Neural coding of color. In E. C. Carterette & M. P. Friedman (Eds.), Handbook of perception (Vol. 5, pp. 156–157). New York: Academic Press.

Gilchrist, A. (2006). Seeing black and white. New York: Oxford University Press. Gilchrist, A. L., Kossyfidis, C., Bonato, F., Agostini, T., Cataliotti, J., Li, X., Spehar, B.,

Annan, V., & Economou, E. (1999). An anchoring theory of lightness perception.

Psychological Review, 106(4), 795–834.

Gori, S., & Stubbs, D. A. (2006). A new set of illusions—the dynamic luminancegradient illusion and the breathing light illusion. Perception, 35(11), 1573–1577.

Helmholtz, H. L. F. von (1866/1924). Treatise on physiological optics. J. P. C. Southall (Transl.). Rochester, New York: Optical Society of America.

Helson, H. (1963). Studies of anomalous contrast and assimilation. Journal of the Optical Society of America, 53, 179–184.

Helson, H. (1964). Adaptationlevel theory. New York: Harper & Row.

Hering, E. (1920/1964). Outlines of a theory of light sense. (Translated by Hurvich, L. M. & Jameson, D.), Cambridge, MA: Harvard University Press, 1964. [Original work published in 1920].

Hurvich, L. M., & Jameson, D. (1966). The perception of brightness and darkness. Boston, Mass.: Allbyn & Bawn.

Hurvich, L. M., & Jameson, D. (1974). Opponent processes as a mode of neural organization. American Psychologist, 29, 88–102.

Jameson, D. & Hurvich, L. M. (1975). From contrast to assimilation: In art and in the eye. Leonardo, 8, 125–131; Reprinted in Henle. M. (Ed.), Vision and artefact (pp. 49–64). New York: Springer.

Joseph, J. S., Chun, M. M., & Nakayama, K. (1997). Attentional requirements in a ‘‘preattentive’ feature search task. Nature, 387, 805–808.

Kanizsa, G. (1954). Il gradiente marginale come fattore dell’ aspetto fenomenico dei colori. Archivio di Psicologia, Neurologia e Psichiatria, 15, 251–264.

Keil, M. S. (2007). Gradient representations and the perception of luminosity. Vision Research, 47, 3360–3372.

Kennedy, J. M. (1976). Sun figure: An illusory diffusive contour resulting from an arrangement of dots. Perception, 5, 479–481.

Kentridge, R., Norman, L., Akins, K., & Heywood, C. (2015). Colour constancy without awareness. Perception, 44(1 suppl.), 274. http://dx.doi.org/10.1177/0301006615598674.

King, D. (1988). Assimilation is due to one perceived whole and contrast is due to two perceived wholes. New Ideas in Psychology, 6, 277–288.

Kingdom, F. A. A. (2011). Lightness, brightness and transparency: A quarter century of new ideas, captivating demonstrations and unrelenting controversy. Vision Research, 51, 652–673.

Kingdom, F. A. A., McCourt, M. E., & Blakeslee, B. (1997). In defence of ‘‘lateral inhibition” as the underlying cause of induced brightness phenomena: A reply to Spehar, Gilchrist and Arend. Vision Research, 37, 1039–1044.

Land, E. H., & McCann, J. J. (1971). The retinex theory of vision. Journal of the Optical Society of America, 61, 1–11.

McCourt, M. E. (1982). A spatial frequency dependent grating induction effect.

Vision Research, 22, 119–134.

Moulden, B., & Kingdom, F. A. A. (1991a). The local border mechanism in grating induction. Vision Research, 31, 1999–2008.

Moulden, B., & Kingdom, F. (1991b). The local border mechanism in brightness induction. Vision Research, 31, 1999–2008.

Reid, C. R., & Shapley, R. (1988). Brightness induction by local contrast and the spatial dependence of assimilation. Vision Research, 28, 115–132.

Riggs, L. A., Ratliff, F., Cornsweet, J. C., & Cornsweet, T. M. N. (1953). The disappearance of steadily fixated visual test objects. Journal of the Optical Society of America, 43, 495–501.

Rudd, M. E. (2010). How attention and contrast gain control interact to regulate lightness contrast and assimilation. Journal of Vision, 10(14), 40. http://dx.doi.org/10.1167/10.14.40.

Rudd, M. E. (2013). Edge integration in achromatic color perception and the lightnessdarkness asymmetry. Journal of Vision, 13(14), 18. http://dx.doi.org/10.1167/13.14.18.

Rudd, M. E. (2014). A cortical edgeintegration model of objectbased lightness computation that explains effects of spatial context and individual differences. Special Issue on ‘‘The Future of Perceptual Illusions: From Phenomenology to Neuroscience”. Frontiers in Human Neuroscience, 8, 640, 1–14; doi: 10.3389/ fnhum.2014.00640.

Shapley, R., & Reid, R. C. (1985). Contrast and assimilation in the perception of brightness. Proceedings of the National Academy of Sciences USA, 82, 5983–5986.

Shevell, S. (2003). Color appearance. In S. Shevell (Ed.), The science of color (pp. 149–190). London: Elsevier Science Ltd..

Soranzo, A., & Agostini, T. (2004). Impossible shadows and lightness constancy.

Perception, 33, 457–465.

Soranzo, A., Galmonte, A., & Agostini, T. (2009). Lightness constancy: Ratio invariance and luminance profile. Attention, Perception, & Psychophysics, 71(3), 463–470.

Soranzo, A., Galmonte, A., & Agostini, T. (2010). Von Bezold effect reverses under stereoscopic conditions. Perception, 39, 592–605.

Troxler, D. (I. P. V.) (1804). Über das Verschwinden gegebener Gegenstände innerhalb unseres Gesichtskreises [On the disappearance of given objects from our visual field]. In K. Himly, & J. A. Schmidt, (Eds.), Ophthalmologische Bibliothek (in German), (Vol. 2 (2), pp. 51–53).

von Bezold, W. (1876). The theory of color in its relation to art and art industry. Boston: L. Prang.

Wertheimer M., 1923/1939 ‘‘Untersuchungen zur Lehre von der Gestalt” Psychologische

Forschung 4 301–350 [Translated as: ‘‘Laws of organization in perceptual forms”, in A Source Book of Gestalt Psychology, Ed. W. D. Ellis (1939, London: Routledge & Kegan Paul)].

White, M. (1979). A new effect of pattern on perceived lightness. Perception, 8, 413–416.

White, M. (1981). The effect of the nature of the surround on the perceived lightness of grey bars within squarewave test gratings. Perception, 10, 215–230.

Zavagno, D. (1996). In O. da Pos, E. Zambianchi (1996). Illusioni ed effetti visivi. Milano: Guerini Studio.

Zavagno, D. (1999). Some new luminancegradient effects. Perception, 28, 835–838.

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