A possible linear filtering model to explain White's illusion at different grating widths

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The perceived lightness of a stimulus depends on its background, a phenomenon known as lightness induction. For instance, the same gray stimulus can look light in one background and dark in another. Moreover, such induction can take place in two directions; in one case, it occurs in the direction of the background lightness known as lightness assimilation, while in the other it occurs opposite to that, known as lightness contrast. The White's illusion is a typical one which does not completely conform to any of these two processes. In this paper, we have quantified the perceptual strength of the White's illusion as a function of the width of the background square grating. Based on our results which also corroborate some earlier studies, we propose a linear filtering model inspired from an earlier work dealing with varying Mach band widths. Our model assumes that the for the White's illusion, where the edges are strong and many in number, and as such the spectrum is rich in high frequency components, the inhibitory surround in the classical Difference-of-Gaussians (DoG) filter gets suppressed, so that the filter essentially reduces to a multi-scale Gaussian one. The simulation results with this model support the present as well as earlier experimental results.

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ABSTRACT

The perceived lightness of a stimulus depends on its background, a phenomenon known as lightness induction. For instance, the same gray stimulus can look light in one background and dark in another. Moreover, such induction can take place in two directions; in one case, it occurs in the direction of the background lightness known as lightness assimilation, while in the other it occurs opposite to that, known as lightness contrast. The White's illusion is a typical one which does not completely conform to any of these two processes. In this paper, we have quantified the perceptual strength of the White's illusion as a function of the width of the background square grating. Based on our results which also corroborate some earlier studies, we propose a linear filtering model inspired from an earlier work dealing with varying Mach band widths. Our model assumes that the for the White's illusion, where the edges are strong and many in number, and as such the spectrum is rich in high frequency components, the inhibitory surround in the classical Difference-of-Gaussians (DoG) filter gets suppressed, so that the filter essentially reduces to a multi-scale Gaussian one. The simulation results with this model support the present as well as earlier experimental results.

INTRODUCTION

Studies of visual illusions generally provide some new insight in the understanding of the process of visual perception by human brain. Though there is no dearth of such studies, many of those are concerned with qualitative analysis only. Comparatively fewer in number are the reports of systematic and quantitative psychometric experiments to measure the dependence of the extent of illusory effects on the variation of some relevant parameters of the figures. Following the footprints of the earlier papers (Shi et al., 2013; Troncoso et al., 2005), we undertake such an experiment on a popular illusion, known as the "White's Illusion" (White, 1979). Though coloured prototypes of almost identical illusions were designed much earlier by Munker (1970) and Gindy (1963), the present paper is confined to the black and white version. White's Illusion, according to its author (White, 2010) is one of the strongest lightness illusions. The term "lightness" merits some discussion. Appearance of an object to the Human Visual System (HVS) depends not only on the luminance (luminous intensity over a given area and direction) but also on the reflectance of the object. Brightness is defined as the "apparent luminance", while lightness is termed as the "apparent reflectance". Brightness ranges from "dim" to "bright". Lightness ranges from "dark" to "light". In this paper "lightness" refers to neutral colours from black to white, through the range of grays, and even if the term perceived brightness occurs in comparison to darkness, it is meant to refer to lightness only, as explained above.

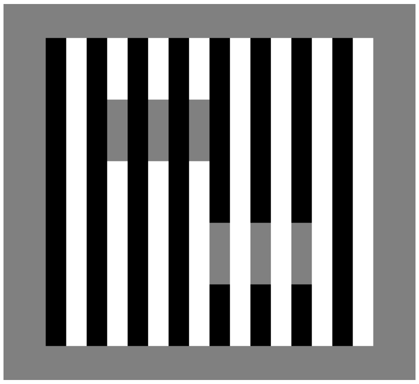

Figure 1: White’s illusion

Figure 1 represents a typical pattern of White illusion (White, 1981). The gray patch on the black bars appears lighter than an identical gray patch on the white bars. It can be noted that in this illusion, the gray target that appears darker are bordered by more black than white, and the targets that appear lighter are bordered by more white than black, and this in fact happens independent of the aspect ratio of the targets.

Many visual illusions (like simultaneous brightness contrast illusion) are explained with the help a concept called *lateral inhibition* (LI), which arose from the pioneering description of the center-surround receptive field (RF) in mammalian retina by Kuffler (1953). Here one assumes that the stimulus generated through the cells of the central region of the RF is inhibited by the cells of the peripheral region of the RF. The concept was further experimentally corroborated by Hubel & Wiesel (1962) and subsequently refined through the theoretical models like ‘Difference of Gaussians’ or DOG (Rodieck and Stone,1965) and ‘Laplacian of Gaussians’ or LOG (Marr, 1982). According to LI, a gray patch surrounded by a dark region appears lighter to HVS than an identical patch surrounded by white region. White’s illusion obviously exhibits properties contrary to the concept of LI. Hence from the very beginning, alternative models were sought to explain the phenomenon. A strong contender to LI is the supposed process of assimilation, in which it is assumed that in HVS there is a tendency to perceive the objects in the colour of their surroundings. Thus a gray object on a dark background appears darker than an identical object in the white background. While the process of LI is subtractive, the process of assimilation is additive. It is further conjectured that LI is computed at the retinal level, while the process of assimilation is accomplished at the cortical level. Interesting aspect of White's illusion is that it does not completely conform either to the process of lateral inhibition or to the process of assimilation. Let us now focus our attention on the previous records of the experimental follow-ups on White's illusion.

Past experiments on White's illusion

Some of the past experiments concerned with White's illusion are reported here. In order to test whether the process of assimilation is the leading factor for the White's illusion, (Kingdom &

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Moulden, 1991) manipulated three inducing bars and a single test bar so that the effect of assimilation may be maximised. Contrary to the expectation, assimilation did not appear to be an important component of the White's effect. They observed that the two test patches differed in brightness instead of lightness. In the same vein (Blakeslee and McCourt, 1999) used the brightness difference in the test patches and observed the effect of changing the phase relationship of the test patch with respect to black bar and white bar. They asserted that the White's illusion is caused by the outputs of anisotropic oriented receptive fields (ODOG model). A new feature was brought out by (Spehar et al., 1995) showing that White's effect may be observed only when the luminance of the test patches lie within the range of luminance of the grating stripes. No explanation is available for the disappearance of the illusion outside the luminance constraint. Moreover, several experiments have shown that if the two target bars are both either lighter or darker than the contextual stripes, the direction of White's illusion gets reversed and becomes identical with the simultaneous contrast. Such a reversed White's effect is termed by (Spehar et al., 1995, 1997) as “the luminance constraint”. The same phenomenon is termed as “double-incremental” and “double-decremental” targets by (Ripamonti and Gerbino, 1997, 2001). Existing models of White's effect focus almost exclusively on the classical version and cannot easily account for the inverted White's effect. Assimilation theory also fails miserably in three variants of White's illusion produced by Anderson (2001, 2003).

It may be noted that in White's illusion, the apparent lightness of the central gray patch changes with the width of the background grating or in other words with spatial frequency as shown in Figure 2.

Figure 2: White’s illusion at 5 different grating widths

Such a study was undertaken by Anstis (2005) using a matching method. Separated from the grating area of White's illusion, a gray patch was adjusted for the perceptual matching. Experiment was performed at five different spatial frequencies, starting from 0.627 cpd to 7.53 cpd (the unit cpd means cycles per degree of visual angle). As the spatial frequency was increased, the apparently lighter patch looked progressively even lighter and the apparently darker patch looked progressively even darker. At the highest spatial frequency, one of the test patches looked 2.5 times lighter than the other patch. Similar results were also obtained for the standard White’s illusion by Blakeslee and McCourt (2004).

Our experiment

In order to quantify the illusory effects of White’s Illusion with variation of grating width, psychometric experiment has been conducted. Three adult males and three adult females are chosen to constitute the subject group. Four of the subjects were naïve while the remaining two subjects were chosen from among the authors. Each experimental session was of duration 30 minutes and 5 such sessions completes a full cycle of experiment. Written consent was obtained from all subjects.

The experimental arrangements were designed identical to that described in Shi et al. (2013), Troncoso et al. (2005). A chinrest was placed 57 cm away from a linearised video monitor (HP Compaq LE 2002X with resolution 1024 x 1024 pixels). During the experiment, subjects rested their heads on it and viewed all the screen images (stimuli) binocularly. Two-alternative forced-choice (2AFC) paradigm, introduced by Fechner in 1889, was used in these lightness discrimination experiments. Visual comparisons between the lightness of a White Illusion stimuli (comparator stimuli) and a graded gray patch (standard stimuli) pasted on a 50% gray background of uniform intensity 128, as shown in Fig. 3(a), were conducted by different subjects. At the beginning of each trial, the subject was instructed to fix attention on a central red cross (1° within a 3.5° fixation window). After a lapse of 1 second, two sets of stimuli (comparator and standard) appeared on the screen simultaneously. One of them was centered at 7° to the left while the other centered at 7° to the right of the central cross.

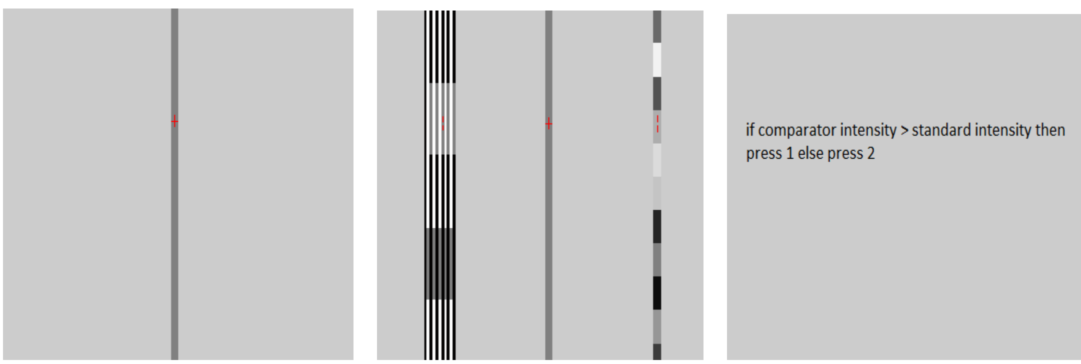


Figure 3(a): Screen design of the psychophysical experiment

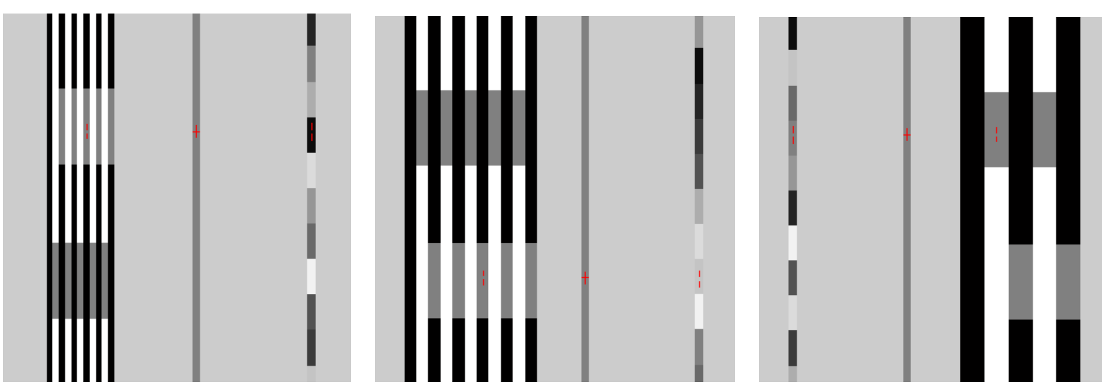


Figure 3(b): Three different stimulus presentations of the lightness discrimination experiment

The White's Illusion stimulus (henceforth to be called as a comparator) was a grating of black and white stripes, in which a portion was partially replaced by a uniform gray rectangle as shown in Fig.1. While designing the stimuli, a relative scale was considered, in which, the intensity of the black stripe was 0%, while that of white stripe and the uniform rectangle were 100% and 50% respectively. In absolute scale, the intensity of the black stripe, white stripe and uniform gray rectangles were 0, 256 and 128 respectively. Within the comparator, the perceived lightness of the gray rectangles were strongly influenced by the lightness of the co-axial bars. It should be further noted that the width of the co-axial bars also had strong influence in modulating the perceived lightness of the gray rectangles. Five possible widths (3.67 cpd, 1.46 cpd, 0.738 cpd, 0.493 cpd and 0.368 cpd) were considered in our experiment. For the smallest width i.e. 3.67 cpd, eleven number of bars could be accommodated within the stimulus, whereas for the largest width i.e. 0.368 cpd, the number of bars had to be reduced to 5. This variation in the number of bars had been done to ensure that the region of comparison always be within 7° around the central cross mark.

The standard stripe on the other hand was divided into 11 segments of varying intensity. The relative luminance of these segments were categorized as 5%, 14%, 23%, 41%, 50%, 59%, 68%, 77%, 86% and 95%. The corresponding intensity values were 11, 23, 36, 59, 82, 105, 128, 150, 173, 196, 219 and 242 respectively. The order of appearance of these 11 segments within the standard bars was scrambled pseudo-randomly. Both the stimuli, i.e. the comparator and the standard, subtended 21° vertically. Two red vertical indicator lines were displayed 6° from the top and the bottom end of both the standard and the comparator, in order to confine the attention of the subject within the specific region of the stimuli to be compared. This is shown pictorially in Fig. 3b for three different cases. As explained above, the vertical red-lines could select any one of the 11 segments in the standard stripe pseudo-randomly with equal probability. It is to be noted further that the red-lines were always aligned with the centre of one of the luminance segments.

The subjects were allowed to be accustomed with the arrangement for a brief period of time. The stimuli appeared on the display for 3 seconds and then disappeared. The subjects had to give their judgments within this period using two keys from the keyboard. Following 2AFC protocol, if the comparator appeared to be lighter than the standard, the subjects had to press Key Number One, otherwise they had to press Key Number Two.

Subjects need not had to wait till the stimuli disappeared from the display, rather they were free to give their judgment as soon as they felt confident. One after another such pairs of stimuli appeared on the display for a duration of 3 seconds and the subjects had to compare the lightness of the comparator stimulus with that of the standard stimulus, which were always positioned exactly at the centre between the inner edges of the red-line markers.

In this process a particular region of interest in the comparator was judged against the parallel segment of the standard. The random choice of the selection of the region of interest ensured unbiased and uniform probability distribution. The difference of luminance between the comparator and the standard, as judged by the subject, is a function of the luminance of the segment within the standard stimulus at the point of comparison. In reality there exists no difference in the luminance of the co-occurring comparator and the standard. Therefore the apparent appearance of the segment of the comparator to be lighter or darker than that of the corresponding segment of the standard is entirely due to the psychophysical effect.

To keep the subjects unbiased, alert and attentive and also to avoid the fatigue during the experiments, various parameters were randomly changed during the display. A number of criteria were used in designing the experimental session as listed below:

(a) The subjects were exposed to a light appearing comparator (co-axial black region) in one half of the trials and a dark appearing comparator (co-axial white region) in the other half of the trials.
(b) The comparator appeared half the time on the left and half the time on the right of the standard during a complete session.
(c) The fixation marker was presented half the time on the top of the screen and half the time at the bottom of the screen randomly
(d) These occur with equal probability.

Several such stimuli are shown in Fig. 3(b). Five experimental sub-sessions completed the full cycle of a session. Throughout a session, the grating frequency of the comparator remained constant. Each subject participated in 5 experimental sessions. The widths of the comparator black and white stripes are designed as 3.67 cpd, 1.46 cpd, 0.738 cpd, 0.493 cpd and 0.368 cpd. A complete session consisted of 150 trials and in each trial, the subjects recorded his\her judgment. The variations introduced in designing the stimuli are listed below in a tabular form in Table 1.

Table 1

Sl No	Stimulus feature	Number of variations	Parameter values/location
1.	Comparator width	5	3.67 cpd, 1.46 cpd, 0.738 cpd, 0.493 cpd and 0.368 cpd
2.	inducing gradient luminance at the point of comparison	2	Gray 50% (128) bar with the coaxial black region. Gray 50% (128) bar with the coaxial white region.
3.	Standard luminance	11	5%, 14%, 23%, 32%, 41%, 50%, 59%, 68%, 77%, 86% and 95% (11,13, 36, 59, 82, 105, 128, 150, 173, 196, 219, 242)
4.	Screen positions	2	Left Right
5.	Fixation cross location	2	Top Bottom

Data Fitting

In the current experiment, following 2AFC protocol, stimuli are generated following the steps given above and the subjects are asked to indicate one of the two choices (either by pressing Key Number One when comparator appears to have different intensity than the standard or by pressing Key number Two otherwise) in response to those stimuli. Such experiments essentially determine the subjective response thresholds of the performers of the experiments, which are essentially the comparator intensities required to produce a given level of performance. Performance of the subjects improves as the comparator intensity is kept more and more away from the intensity of the standard. These experiments also record the rate at which the performance is improved. Purpose of these experiments is to measure two main parameters, namely: "point of subjective equality" (PSE) i.e. when the intensities of the comparator and the standard appear to be same to the subject and the subjective ability to discriminate between the intensities of the comparator and the standard. The former is known as "bias", while the later is known as "discrimination ability".

Psychometric curves, given in Fig. 4(a) are obtained by fitting the data with logistic functions using a maximum likelihood procedure. The function FitPsycheCurveLogit (used in MATLAB) is designed to fit a basic psychometric curve using a general linear model with a logit link function. The function uses *glmfit* to fit a binomial distribution with a logit link function. It is basically a cumulative Gaussian. The mean and variance of the Gaussian are assigned as the subject bias and subjective discrimination threshold. The function may take up to four input parameters, namely, the luminance difference between standard and comparator along X axis, perceived lightness of comparator as compared with the data along Y axis, the weights for each points and targets.

We have also fitted the data with a modified function, developed by Wichmann and Hill (2001). They presented a cumulative Gaussian function with four parameters for fitting a psychometric function. These are mean, standard deviation, guess rate (g) and lapse rate (l). The parameters g and l constrain the limits of the cumulative distribution that provides the sigmoid shape for the psychometric curve. The plot of the same set of average psychometric data is shown in Fig. 4(b). It is observed that the psychometric curves remain almost unaffected by this modification, though the family of curves appears to be more compact.

We have also plotted in Fig. 4(c), the illusory enhancement with the stimulus widths. The perceived enhancement of lightness and darkness perception decreases as the stimulus width increases. The result is qualitatively similar to that obtained in Anstis (2005).

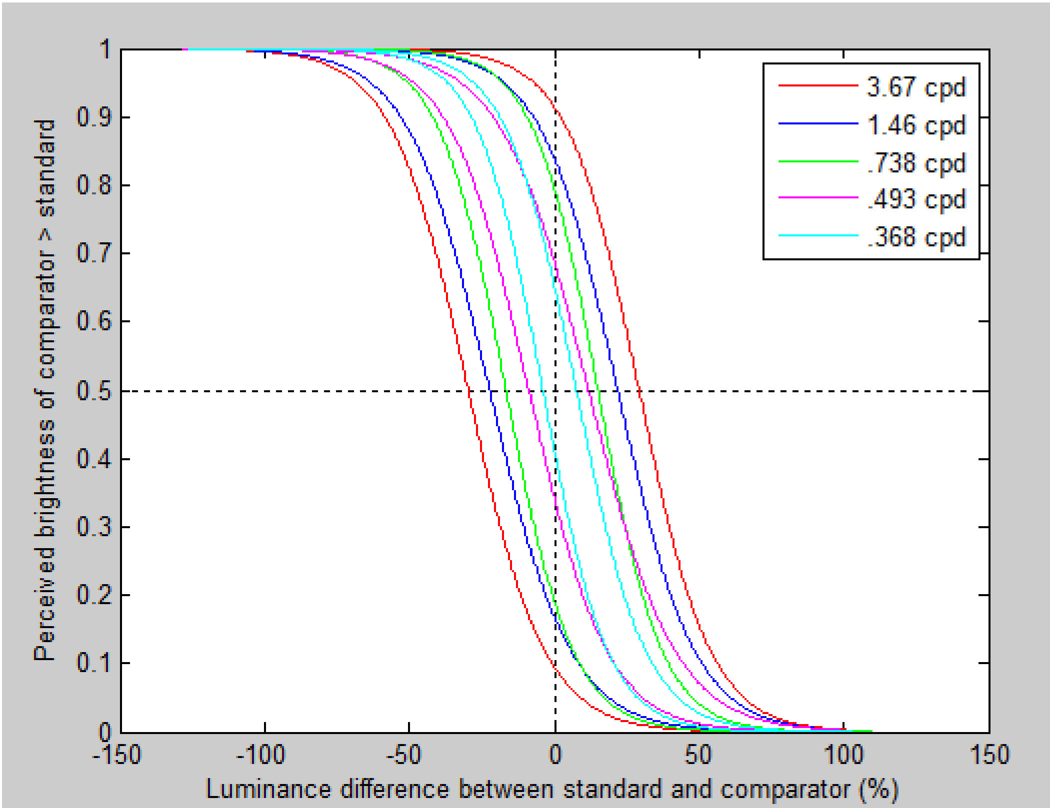


Figure 4(a): Psychophysical experimental result: Average Psychometric functions for the different stimulus widths are displayed in different colors. For a particular stimulus width, the upper curve represent the condition when the comparator appears bright and the lower curve represents the condition when the comparator appears dark. While drawing the Psychometric function, a pair of curves are placed symmetrically against the luminance difference value of 0.

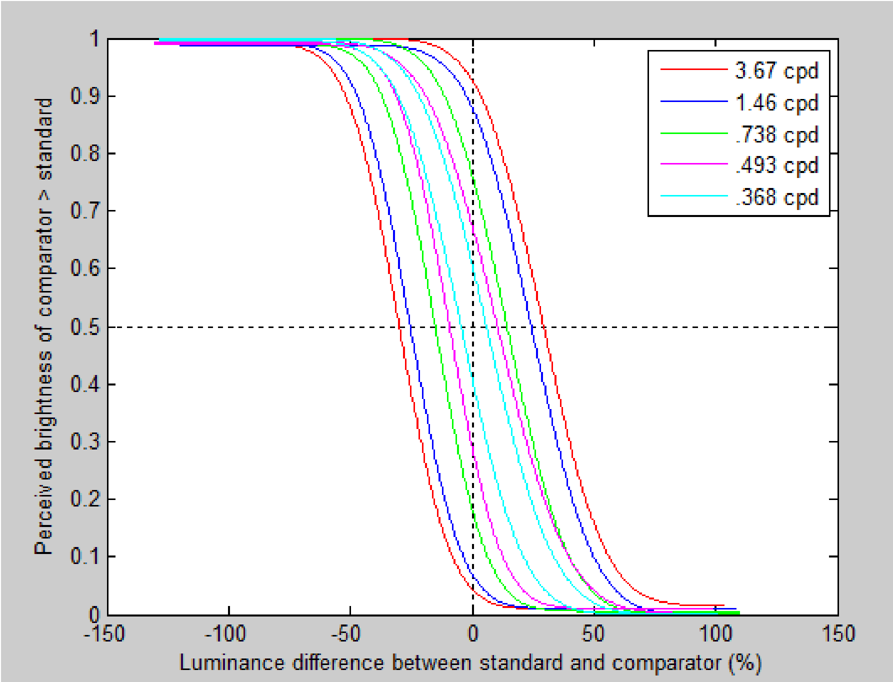


Figure 4(b): Psychophysical experimental result: Average Psychometric functions for the different stimulus widths are fitted using *FitPsycheCurveWH* fitted function developed by Wichmann and Hill psychometric function.

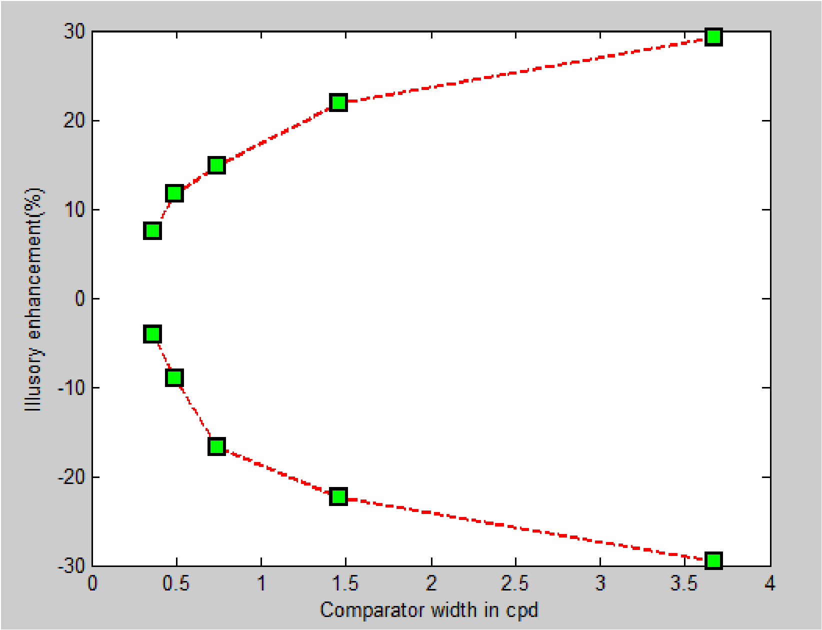


Figure 4(c): Perceived enhancement of the points of subjective equality (PSE) for different stimulus widths, with respect to the physical luminance of the comparator.

Linear Filtering method in explaining White Illusion

The linear filter model of different visual phenomena is a well established branch of psychophysics. Cellular connectionist model based on classical receptive field and the lateral inhibitory process have already been used in developing model for various visual phenomena associated with lightness illusions (Macknik, Martinez-Conde and Haglund,2000; Troncoso, Macknik and Martinez-Conde, 2005; Troncoso et.al., 2007; Troncoso, Macknik and Martinez-Conde, 2009).

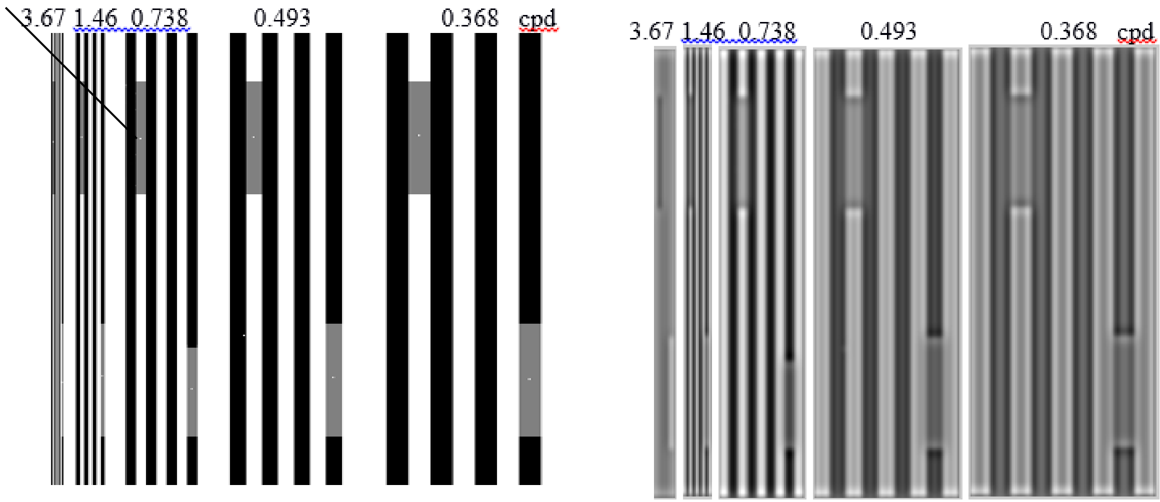
In the literature, the Difference of Gaussian function (DoG) is well accepted as the model of the classical receptive field in different layers of the visual pathway. All the visual phenomena associated with the simultaneous contrast (SBC) have already been explained using DoG based simulation (Shi et al., 2013). The same type of simulation is either found inappropriate in case of White's Illusion or, there is unavailability of simulation result in case of White's Illusion stimuli having different grating frequency. At this juncture, the result of simulation is being presented to explain White's Illusions with different widths using receptive field filter with and without lateral inhibitory process.

In DoG model, the kernel of the filter is represented by the difference between the excitatory centre and the inhibitory surround, given as:

Receptive-field(x,y) = Centre(x,y) – Surround (x,y)

$$= \frac{k_c}{\sqrt{2\Pi\sigma_c^2}} e^{-[x^2+y^2]/2\sigma_c^2} - \frac{k_s}{\sqrt{2\Pi\sigma_s^2}} e^{-[x^2+y^2]/2\sigma_s^2}$$

There are four free parameters in the expression of the DoG kernel. σ_c and σ_s are the space constants of the centre and the surrounds, while k_c and k_s are the excitatory and inhibitory gain, respectively. In our simulation, these are set as (i) σ_c =0.8, σ_s= 5, k_c = 1, k_s =0.8 (ii) σ_c =2, σ_s= 4, $k_c = k_s$ =1, and (iii) σ_c =0.8, σ_s= 5, k_c = 1, k_s =0.25. Thus five stimuli representing White's illusion of different widths are prepared and they are convolved with DoG having different free parameters. For biological relevance, generally, we take center-width < surround-width and excitatory-gain > inhibitory-gain. This we have maintained. However, as in Shi et al. (2013), we have, for the sake of mathematical exploration, also considered one case where the peak sensitivities (i.e. k_c and k_s) are equal. Different stimulus and the convolution results are presented in Fig. 5(a) and Fig. 5(b) respectively.



LEFT RIGHT

Figure 5(a): Left: Computational simulation with a DoG filter. Five stimuli of different widths and intensity plot of their convolved values are illustrated. These stimuli are equivalent to the comparators presented in the psychophysical experiment. The white dots denote the regions of comparison during the psychophysical experiments. Right: Predicted response from a DOG filter, which has been generated by convolving the DOG filter with parameters σ_c = 2 ,σ_s = 4, k_c = 1 and k_s = 1.

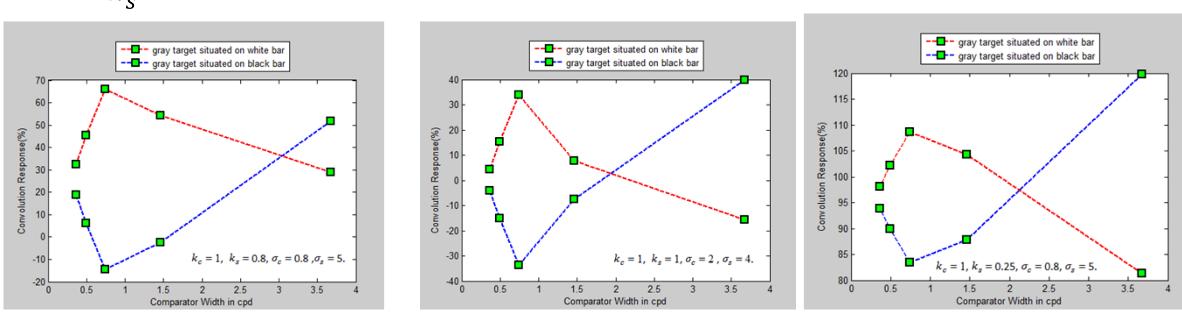
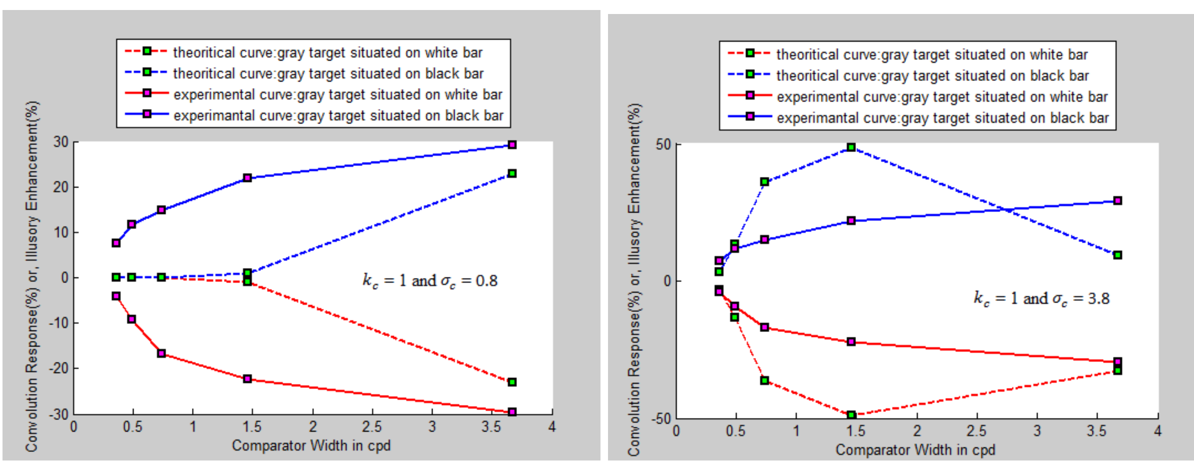


Figure 5(b): Convolution output with a DoG filter, for different combinations of filter parameters. Convolved output, at the point of discrimination, as explained by the white dots in Figure 5(a), in the psychophysical experiment for each width, has been plotted.

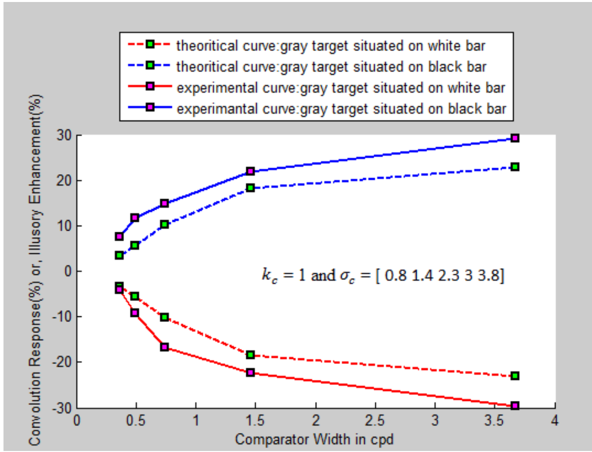
It is observed from Fig. 5(a) and 5(b) that the DoG filter based simulation cannot reproduce the psychophysical experimental result presented in Fig. 4(c). The present authors (Mazumdar et al., 2016) have faced similar problems while simulating the Mach band illusion with DoG filter. We have observed that any simulation, with a DoG filter having fixed values of the space constants for both excitatory and inhibitory Gaussians, leads to wrong predictions as the sharpness of discontinuity in the intensity profile of the Mach band is increased. Much better simulation may be obtained if the space constant of the inhibitory Gaussian is reduced with the sharpness of discontinuity. In case of step edge (i.e. at the sharpest discontinuity) no Mach band is observed, an event which may be simulated by assuming the space constant of the inhibitory Gaussian to be zero. We, therefore, conjecture that there are situations in which the HVS prefers to filter with a single Gaussian rather than DoG. Since the sharp edge is mostly populated with high frequency components, we may further assume that images with large proportion of high frequency spectrum are filtered by HVS with a single Gaussian or in other words simply by smoothening the picture.

In the light of the above, it may be stated that White Illusion stimuli (whose visual response cannot be simulated through DoG filter) have more high frequency components in its spectrum in comparison to, for example, any Simultaneous Brightness Contrast stimulus (whose visual response is well reproduced through a DoG filter). We have, therefore, tried to simulate the effects of White's illusion with a single excitatory Gaussian filter. In choosing the space constant, we observe that the value of the appropriate σ_c depends on the value of the grating frequencies for realistic simulation. The filter outputs at the point of discrimination for different widths are plotted in Figure 6. It may be noted by comparing the Figure 6(a) with Fig. 4(c), that simulation with small value of space constant (σ_c), yields better agreement with the psychometric curves at higher grating frequencies, but fails at lower grating frequencies. For large values of σ_c, the opposite behavior is observed, as is shown in Figure 6 (b). Finally the filter output for White's illusion of different grating frequencies are generated with variable σ_c . The results are plotted in Figure 6 (c). The simulation curve fitted well with the experimental psychophysical curve.

As shown in Figure 4 (a) and (b), when the gray patch is placed in the background of the white grating, the illusory enhancement, shown in Figure 6 is negative as obtained in the experimental psychometric curve. The same is true when the gray target is placed on the black grating.



(a) (b)



(c)

Figure 6: Variation of the Illusory enhancement (%) or, the Convolution Response (%) with the frequency of the grating are plotted. X-axis represents the grating frequency in cpd. Illusory Enhancement (in %) for experimental data or, Convolution Response (in %) for simulation data are plotted along the Y-axis. The simulated data has been normalized against the intensity value of 128. The continuous curves represent the experimental results while the dotted curves are the outcome of the computer simulation. The free parameters k_c and σ_c corresponding to the amplitude and spatial width of the Gaussian filters are varied in three different cases. k_c = 1,1,1 and σ_c = 0.8, 3.8, [0.8 1.4 2.3 3 3.8] in Fig. 6(a), 6(b) and 6(c) respectively. Thus in Figure 6(c), the value of the standard deviation for simulated data varies with the grating frequency.

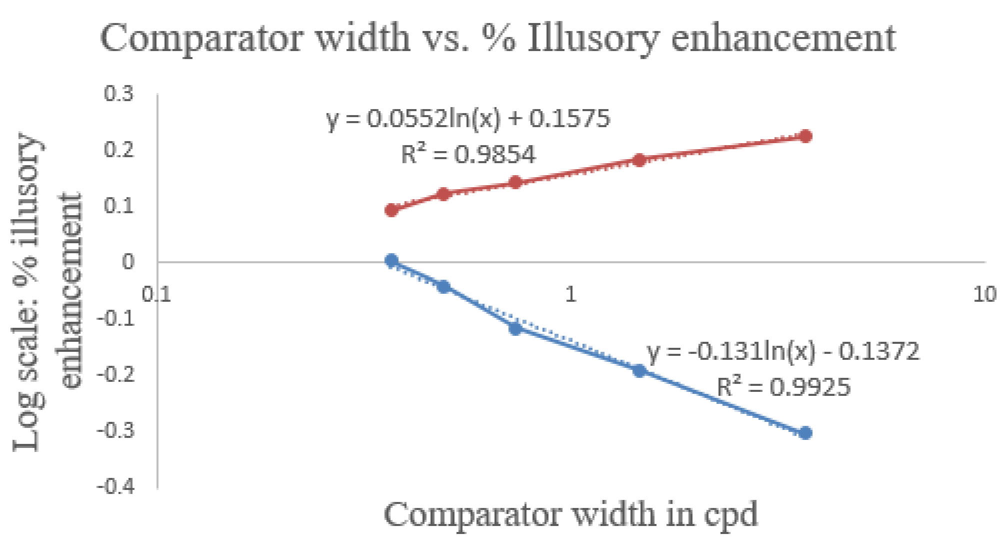


Figure 7: Experimental data on % illusory enhancement as a function of grating frequency plotted in the logarithmic scale. The log of % illusory enhancement data has been taken before normalization within 0 and 2.

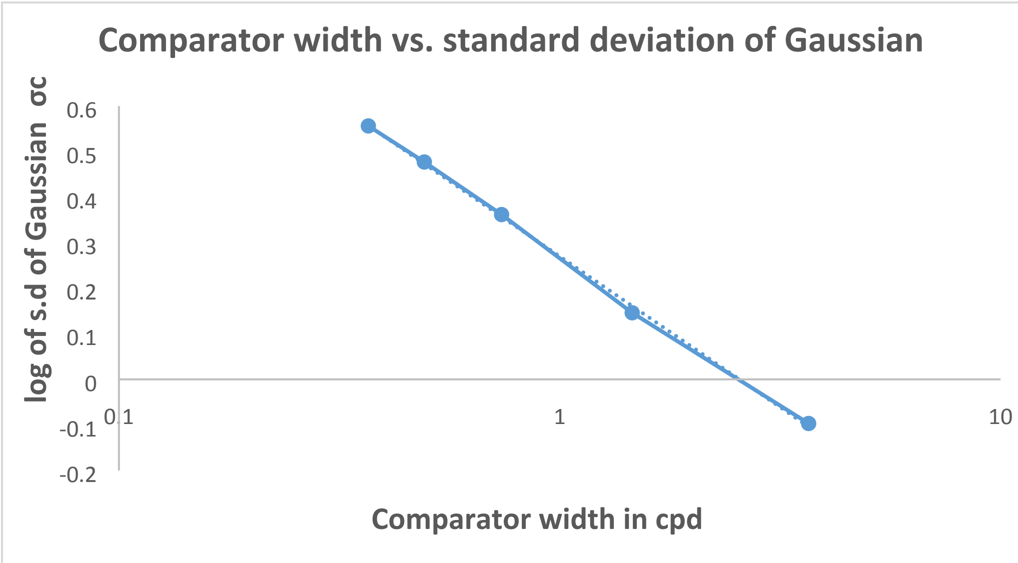


Figure 8: Variation of the scale factor of the suppression region with the grating frequency has been plotted. The comparator width has been plotted in the logarithmic scale. The nature of the graph shows close resemblance with that of Figure 7

Discussion

It is well known that the simultaneous brightness contrast (SBC) and the White's illusion (WI) show strikingly contrastive behavior so far as lateral inhibition phenomena is concerned. Psychometric data on SBC (Shi et al., 2013), can be explained using a DoG based linear filter model. However, WI cannot be explained by invoking the principle of lateral inhibition. We propose a linear filter model in which the lateral inhibition part of the centre surround model is adaptive in nature. Previously we had used a similar model (Mazumdar et. al., 2016) to explain the variation of the width of Mach bands with the sharpness of discontinuity in the intensity profile of an edge. A Fourier analysis based adaptive model was proposed to show that the effect of surround suppression had to be reduced as the contrast at the edge increased. In the extreme limit of binary edges, where the contrast is maximum and represented by a step edge, no lateral inhibition takes place, so that over there the DoG kernel gets converted into a Gaussian kernel without any surround. It should be noted here that the spectrum of step edges are very rich with high frequency components.

Extending the argument in case of White's illusion, where the edges are strong and many in number, and hence the spectrum is rich in high frequency components, we propose a Gaussian kernel to explain the visual process in the framework of a linear filter method. The methodology of fixing the values of σ_c in this linear filter has been described above. In Fig. 7, we have plotted the logarithm of percentage illusory enhancement, as measured from our experiments, with the grating frequency or cpd (in a log scale). The linear nature of the variation bears close similarity with the graph shown in figure 1.1(b) of Anstis (2005). We further plot in Figure 8, the variation of the logarithm of the fitted scale factors of the effective receptive field with the grating frequency in the logarithmic scale. The linear variation in the graph shows a striking similarity with the linearity exhibited in Figure 7. This shows a possibility of fixing the values of the scale factors from the measured values of perceived lightness, instead of treating those as free parameters. If that possibility is realizable, it would build up a self consistent model for explaining the perception by HVS of the images, which are rich in high frequency components. Although the Oriented Difference of Gaussians (ODOG) filter of Blakeslee and McCourt (1999, 2004) have made a similar attempt achieving success to quite an extent, Bakshi & Ghosh (2012) and Bakshi et al. (2016) have already shown the limitations of this model of lightness perception in explaining illusory effects beyond certain scales. Moreover, there is no known neural correlate of the contrast normalization step in Blakeslee and McCourt's algorithm. In contrast, multi-scale filtering is a well accepted fact for neuroscientists and psychologists alike.

The present work thus attempts to set up a connectivity between a) the multi-width SBC illusion, that was explained with DoG filter (Shi et al., 2013), b) the multi-scale White effect, that has been explained here with Gaussian filter, and c) the varying gradient based multi-width Mach band illusion (Bakshi & Ghosh, 2012) that has to be explained by a combination of these two filters, i.e. the DoG and the Gaussian (Mazumdar et al., 2016). However, a lot more data are to be collected to arrive at a unified model. We have an intention of moving towards that end through our future work. Similar attempts from different other perspectives are also being made by contemporary researchers to fulfill the goal of combining edge information (from derivative or difference operation) and multi-scale integration (Rudd & Zemach 2004, 2005), a dream that was propagated decades ago by David Marr (1982) and some other researchers (Young, 1987).

Additional Information and Declarations

Competing Interests

The authors do not have any competing interest

Author Contributions

Soma Mitra conceived and designed the experiments, performed the experiments, analyzed the data, wrote the paper, ran computational simulations.
Debasis Mazumdar performed the experiments.
Debasis Mazumdar, Kuntal Ghosh and Kamales Bhaumik conceived and designed the experiments, analyzed the data, wrote the paper.

Ethics

The authors have followed the COPE guidelines for ethical responsibilities and written consent was obtained from all subjects.

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