Lightness Perception on Noise Backgrounds Considering Background Frequency and Stimulus Size

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Abstract

Schirillo & Shevell (1996) showed that stimuli on spatially complex backgrounds look dimmer than the same stimuli on a uniform background. However, this effect was only observed if the luminance of the stimulus was higher than the average luminance of the background. A psychophysical experiment was completed in which observers chose the lighter of a pair patches on noise and uniform backgrounds to determine the equivalent lightness perception across different spatial background configuration. Three noise patterns, white noise, high frequency noise and low frequency noise, were used in the background setup. The variance of the noise pattern luminance was kept constant. Experimental setup use different stimuli size, different dynamic range of the noise background and different lightness of the peripheral area. The results of this research will be used to better understand lightness perception in images and develop algorithms for image-contrast reproduction across changes in background and surround.

Introduction

In the concept of equivalent background [1], the adaptation field of a complex image can be treated as a visually equivalent uniform patch by either linear or nonlinear luminance integration. Another similar integration is the gray world hypothesis [2], which was very commonly used in chromatic domain. However, the spatial property in the complex scene will affect the image contrast perception in different ways.

Some previous researches showed different results and interpretations under different experimental configurations. Zaidi et al. [3] [4] [5] tested the brightness induction under uniform and complex surrounds. They proposed the contrast control model for their result. In their model, the high contrast variegated background would lower the perceptual contrast of the gray patches. That means the light patches on variegated background would looks darker than on the equivalent uniform background and vice versa. Adelson [6] proposed the Atmospheric Transfer Function (ATF) that was used to map perceived reflectance and luminance. The ATF could be described as a gain and offset model. But there was no limitation for choosing these two parameters; this will result in either contrast gain (perceived contrast increases with contrast) or contrast loss (perceived contrast decreases with contrast). Schirillo and Shevell [7] explored another interesting result. Their results showed that stimuli on the spatially complex background (checkerboard) look dimmer than the same stimuli on the equivalent uniform background; however this effect was only observed if the luminance of the stimulus was higher than the integrated average luminance of the background. They used various spatial vision models to explain the results.

It is well understood that human visual system perceived the lightness in a relative way, but this cannot solve the entire lightness perception problem. For example, if one observer can determine the brightness ratio of two patches are four to one. But that is not enough to determine whether these two patches are 80% and 20% gray or they are 20% and 5% dark gray. This will introduce another issue in the lightness perception: anchoring problem. For absolute judgments, one must use a gray scale with an anchor that is a luminance mapped to a standard lightness value such as mid-gray or white.

Land and McCann [8] proposed the highest-luminance rule in their Retinex theory. In their theory, the highest luminance would be anchored to white. All other luminance level should be rescaled relative to that white. Gilchrist and coworkers [9] [10] found another anchoring rule. In their new anchoring theory, the largest area tends to appear white. In their testing experiments, they painted the inside of a large hemispherical dome with two shades of gray paint. The observers only have two luminances in the entire visual field. They found the lighter part would be perceived as luminosity or self-luminous surfaces if the area of lighter part were much less than 50% of the visual fields. And this is directly contradicts the highest luminance rule. For the complex images, anchoring occurs within the framework that is a region containing stimuli that are grouped. The insulated frameworks can be either global or local. The key concept of this theory is the compromise between the lightness values in local frame and the value in the global framework.

This research presented in this paper directly extended Schirillo and Shevell's experiment, and tried to use Gilchrist's new area rule to explain the phenomena observed in the experiment. Based on Gilchrist's area rule, we can assume that the observer would locally anchor the large area of uniform background as white and perceive the stimuli as self-luminous on the uniform background when the stimuli was lighter than the uniform background. But on the complex background side, the local white information will inhibit this effect on the same stimuli. As a result stimuli on the uniform background would be perceived lighter than the same stimuli on the complex background if its luminance were higher than the luminance of background. But for the stimuli with luminance lower than the background, there would be no self-luminous perception on both sides, so they would be match in perceived lightness.

In this research, serial psychophysical experiments were developed to verify the assumption of the self-luminous on the lightness perception across different backgrounds. Three noise patterns, white noise, high frequency noise and low frequency noise, were used in the background setup. Further it was hoped that the result would be used to better understand lightness perception in the image appearance and develop the algorithms for image-contrast reproduction across the changes in background and surround.

Experimental

The experiment was designed based on the hypothesis that the stimuli in the uniform background will have some self-luminous appearance if it is lighter than background. As the result, the lightness perception of the stimuli will not be matched with the same stimuli in complex background. In order to test the correctness of this assumption, two experiments were run.

In both experiments, observers were asked to choose the lighter of a pair patches on noise and uniform backgrounds to determine the equivalent lightness perception across different spatial background configuration. The experiments were implemented in MATLAB, using Quest procedure in Brainard's Psychophysics Toolbox extensions [11]. An example of the stimulus and interface configuration for this experiment is shown in Fig 1. In the experimental interface, the left side disc is the uniform background, and the right side disc is the noise background. In both experiments, the observers were sitting in front of LCD display about 60 cm away. The viewing angle of the center stimuli is about 2-degree or 1-degree in different experimental sections. The viewing angle of each background disc is 20-degree diameter. The size selection was based on the result from Yamaguchi [12]. Two experiments used two different dynamic ranges of the LCD display in the noise background configuration and relative luminance of the testing stimuli.

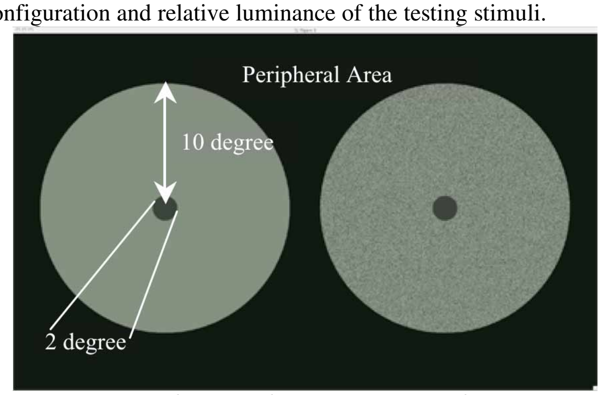


Figure 1. Example configuration of the experimental interface.

A total of 10 observers with normal or corrected-to-normal visual acuity participated in the experiments. Nine of them participate in experiment one; ten observers took experiment two. Two of the subjects repeated both experiments five times.

The experiments were run on an Apple Cinema HD LCD Display with the maximum luminance of 200 cd/m^2. This 23-inch LCD display has a 1920 by 1200 resolution. The display was carefully characterized using the colorimetric characterization model by Day [13]. The experiments were set up in a dark room.

In the first experiment, three different achromatic noise background patterns, white noise, high spatial frequency noise and low spatial frequency noise, were used. All three noise patterns used the whole dynamic range of the LCD display (range from 0 to 100 in relative luminance). In this experiment, the mean relative luminance value for each noise background was set to 50 out of 100. This is same as the relative luminance value of the uniform background. For each kind of noise pattern, there were two noise backgrounds with different luminance variance: 256 and 64. The different variance would make the image with different complexity and provide different local white information. There were six different spatial noise configurations: combination of three frequencies and two variances. Table one shows the combination of the noise type and variance used in the experiment one. The lightness (L*) of the peripheral area, which was the area outside two discs on the Display, was set to 20% of the LCD white point. Basically, this experiment is very similar to Schirillo & Shevell's experiment except the noise pattern backgrounds were used here instead of using checkerboard backgrounds.

Table 1. Noise Types in Experiment One. Mean relative luminance level is 50 out of 100, and the lightness (L*) of peripheral is 20% of Display White.

Noise Type	White Noise	High Fq.	Low Fq.
Noise Variance (relative Lum. 0~100)	64	64	64
	256	256	256

In experiment one, five different relative luminance levels ranging from 11 to 76 were chosen as the stimuli luminance level. The lightness (in CIELAB space) levels for these five stimuli were evenly distributed in the lightness range from 40 to 90. Based on some preliminary experiments, the results show that the observer will match the stimuli very well across different backgrounds when the relative luminance is low. So in this experiment, the low luminance levels were not tested. And the high luminance stimuli were not tested because the Quest procedure will not be accurate when the luminance of the stimuli close to upper bound of LCD dynamic range.

Table 2. Noise Types in the Experiment two. Mean relative luminance level is 50 out of 100.

Pattern Type	Stimuli Size	Variance	Peripheral Lightness	Mean relative Lum.
Type I	2 degree	256	20%	30
Type II	2 degree	64	20%	30
Type III	2 degree	256	100%	30
Type IV	2 degree	64	100%	30
Type V	1 degree	256	20%	30
Type VI	1 degree	64	20%	30
Type VII	2 degree	Image	20%	Close to 30

Note: the peripheral lightness is the percentage of the maximum white in noise background.

In experiment two, only white noise patterns were used in the experiment. The noise patterns used low 60% part of the dynamic range of the LCD display (from 0 to 60). In this experiment, the mean relative luminance value of the noise background was set to 30. The relative luminance of the uniform background was also set to 30, which was supposed to be equivalent background of the noise background. Two different luminance variance (256 and 64) of the noise background were tested in experiment two. Two different sizes of stimuli were tested in experiment two: 1 degree and 2 degree viewing angle. Two different lightness level of the peripheral area were tested. One peripheral lightness level is equivalent to 20% of the maximum lightness in the noise background or the local white information. Another peripheral lightness level is the lightness equal to the maximum lightness in the noise background. The peripheral area lightness provides the global white information in this case. There was one short section in this experiment, which test the stimuli in the real image instead of noise background. Table 2 shows the combinations of the stimuli size, variance and the peripheral lightness were used in the experiment two.

In experiment two, six different relative luminance levels ranging from 6 to 76 were chosen. One of the six stimuli has the same relative luminance as the maximum luminance in noise background, and one of the six stimuli has the relative luminance higher than the maximum luminance in noise background. The lightness levels for these six stimuli were distributed in the lightness range from 30 to 90.

Results and Discussion

Experiment One

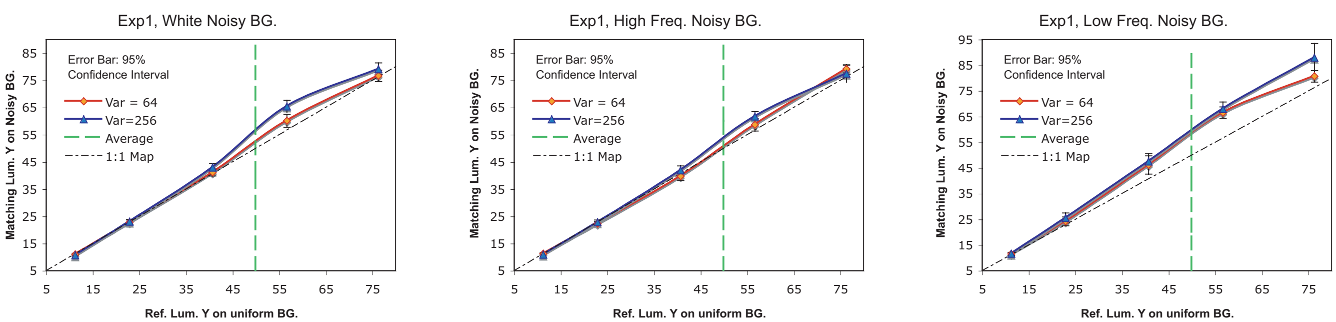
In experiment one, there were six different types of noise background. The relative luminance range of the background covered the whole dynamic range of LCD. Figure 2 shows the relationship between the relative luminance levels of the stimuli on noise background and the corresponding relative luminance levels of the reference stimuli on uniform background. The error bar shows in Figure 2 is the 95% confidence interval. Figure 2 (a), (b), and (c) show the experimental result, respectively on white noise, high frequency noise, and low frequency noise background.

On all three different noise backgrounds, experimental results shows similar trend. That trend shows that the observers will match the reference stimuli on uniform background by using almost the same luminance on noise background when the reference stimuli is lower than the average luminance or the luminance on uniform background; the observers tend to use higher luminance level to match the reference stimuli on uniform background. This result agrees with Schirillo & Shevell's result. There was one exception case. Figure 2 (c) shows that the third testing stimulus was not matched to the reference stimulus on the uniform background. The possible reason might be the strongest local white in low frequency noise pattern causing some simultaneous contrast effect.

This result confirms the assumption that the stimuli on the uniform background will become self-luminous appearing, but the local white information on the noise background will inhibit this self-luminous effect. As the result, the observer will perceive the stimuli on the noise background have lower lightness than the same stimuli on the uniform background when it is above the average. This implies that the equivalent adaptation background of the elements in image could be different from the local linear integration when the luminances of these elements are higher than its local average.

The experimental result also shows that the bigger variance of the noise background will increase this mis-match effect across different backgrounds in all three cases. In Figure 2, blue lines show the large variance and red lines show the small variance. This implies that this mis-match effect will depend on the image complexity.

By comparing the results in Figure 1 (a), (b), and (c), it could be concluded that the mis-match effect between different backgrounds is most significant in low frequency noise background and least significant in high frequency noise background. This is not a surprise. It can be explained that human vision system will blur the white information in high frequency image and make it look more like the uniform background. The low frequency noise pattern contains more local white information, which will inhibit the self-luminous effect on the noise background side.



(a) (b) (c)

Figure 2. Relationship between the relative luminance of the stimuli on noise background and the relative luminance of the reference stimuli on uniform background. The subfigure (a), (b) and (c) represent the experimental result, respectively on white noise, high frequency noise, and low frequency noise background.

Experiment Two

The result in experiment one shows that the self-luminous effect on uniform background can be used to explain the mis-match across different backgrounds. On the complex background side, the self-luminous effect of the stimuli was inhibited by the local white information of the noise background. The previous experiments only test the stimuli with luminance lower than the maximum luminance of the complex background. But it is still unknown what will happen if the stimulus is lighter than the local white. In this case, the assumption is that the perceived lightness of the stimuli on both sides will have the self-luminous effect. As the result, the same stimuli will be perceived as same or similar lightness. Experiment two was designed to test this assumption.

Figure 3 shows the experimental results in experiment two. The error bar shows in Figure 3 is the 95% confidence interval. Figure 3 (a) shows the relationship between the relative luminance levels of the stimuli on noise background and the corresponding relative luminance levels of the reference stimuli on uniform background. The noise background is Type I and II listed in Table 2. In experiment two, only 60% dynamic range was used. When the relative luminance of the stimuli is lower than the maximum luminance of the noise background (from 0 to 60), result shows the same trend as in experiment one. But for the stimuli with luminance level higher than local white, the result shows that the observer will perceive the same stimuli as same lightness across different backgrounds. This result proves the above assumption that the self-luminous effect will happen in both sides and the lightness of the same stimulus will be matched across different background when this stimulus is lighter than the local white. Figure 3 (a) also confirms that the lightness mis-match between the different backgrounds depends on the image complexity.

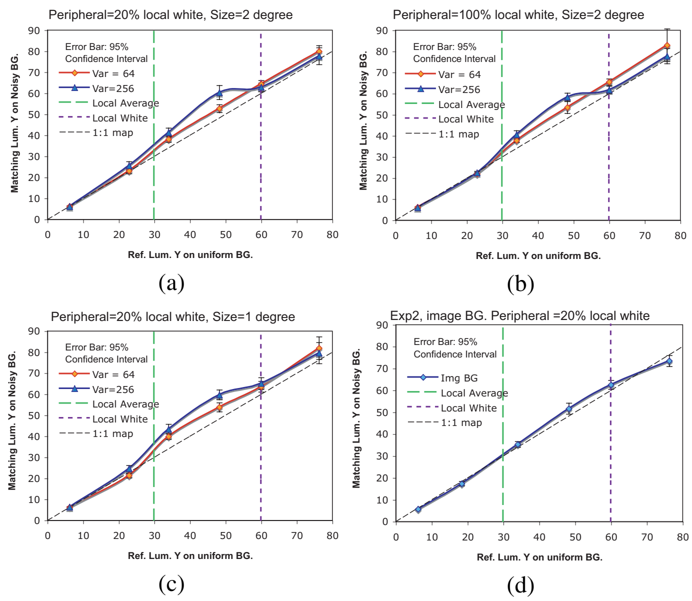


Figure 3. Experimental result in experiment two. The subfigure (a) represents the experimental result on peripheral area with 20% local white and 2° stimuli. The subfigure (b) represents the result on peripheral area with 100% local white and 2° stimuli. The subfigure (c) represents the result on peripheral area with 20% local white and 1° stimuli. And the subfigure (d) represents the result on the real image as the background.

Figure 3 (b) shows the similar relationship in Figure3 (a), but the lightness of the peripheral area is same as the noise background local white. This was defined in Table as Type III and IV. In this experimental setup, the lightness of the peripheral area served as the global white because it has biggest area in the whole display. According to Gilchrist's anchoring theory, the largest area tends to be perceived as the white anchor. But by comparing the result in Figure 3 (a) and (b), it is found that there is no very significant difference. This result indicates that the self-luminous effect is most depends on local area. The local white information determines this self-luminous effect, while the global white could not inhibit this effect completely.

Figure 3 (c) shows the experimental result using stimuli with one-degree viewing angle on both uniform and noise backgrounds. Comparing the result in Figure 3 (c) and (a), there is no big difference. Although previous research shows that the lightness perception depends on the size of the stimuli. In this experiment, the result can be explained that the stimuli with different size could be perceived as different lightness, but the differences are same on both sides. As the result, the matching curve did not change.

Figure 3 (d) shows the experimental result testing the stimuli on real achromatic image and uniform background. The mean luminance of the image was same as the uniform background. The result shows that the same trend in the experiment using noise background. But the mis-match effect is not as big as in noise background case. This makes sense because the noise image is the most irregular image. And real image contains a lot of meaningful information, i.e. sky or light. The meaningful white will serve as real local white. But this local white in the testing image is not as strong as in the noise image.

Conclusions

A psychophysical experiment was completed to determine the equivalent lightness perception across different spatial background configuration. The experimental results showed that stimuli on spatially complex backgrounds look dimmer than the same stimuli on a uniform background. However, this effect was only observed if the luminance of the stimulus was higher than the average luminance of the background. This result can be explained by a self-luminous appearance of the stimuli on the uniform background when it is higher than the background, while the white information on the complex side inhibited this effect. The results also showed that this effect depended on image complexity. For the stimuli with luminance higher than the local white in the complex background, this mis-match was decreased.

In the future research, the result can be used to model the equivalent background in the image appearance model. Further it is hoped that the result will help better understand lightness perception in the image appearance and develop the algorithms for image-contrast reproduction across the changes in background and surround.

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