THE IMPACT OF LUMINANCE CONTRAST ON ATTENTION AND MEMORY

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ABSTRACT

Previous studies have found that luminance contrast may enhance attention and attention is positively correlated with memory. However, little attention has been given to understand the impact of luminance contrast on memory. The present study attempts to address this gap by examining the effect of luminance contrast on attention and memory. A total of 159 undergraduates were randomly assigned to three luminance contrast conditions (high vs. moderate vs. low) and were administered a modified d2 test and modified words memory test. Multivariate analysis of variance showed significant effect of luminance contrast on memory performance. Participants in the high and moderate luminance contrast groups recalled more words than counterparts in the low contrast group. However, the effect of luminance contrast on attention was not significant, though planned comparison found that high contrast group scored higher than low contrast group. The findings not only shed light on improvement of memory but also have implication for design and marketing and consumer behaviours study.

Keywords: luminance contrast, selective attention, memory

INTRODUCTION

What was the last advertisement you saw before reading this article? The average number of advertisement an individual exposed for a day is more than 1,500 (Walia, 2012). However, people can only pay attention to less than 70 of them and remember only 5 to 10 ads (Kotler, Bowen, & Makens as cited in Kim, 2010). This phenomenon can be explained by the selective attention theory. The theory posits that irrelevant information is being ignored due to the limited capacity in the processing information (Lavie, Hirst, Fockert, & Viding, 2004). Hence, individual's selective attention on advertisement makes it difficult for the marketers and advertiser to keep consumer's attentions (Kim, 2010).

Colour has been found to have impacts on moods and emotions, consumers' perceptions and behaviour (Aslam, 2006), and attention (Hollingworth & Hwang, 2013; Warner & Schaie, 1964). Warm colours (e.g., red) basically generate more arousal and attention than cool colours (e.g., blue) (Birren, 1978), while cool colours create greater relaxation and pleasure than warm colours (Jabocs & Seuss, 1975). In addition, the background colour of the text has also been found to influence recalling rate (Mehta & Zhu, 2009; Mustafar & Dzulkifli, 2012). Colour and advertising studies suggest that background colour effects are qualified by luminance contrast: the contrast between the background colour and the colour of the contents (Fernandez & Rosen, 2000; Hall & Hanna, 2004).

Although there are studies on the effect of luminance contrast on attention (Pashler, Dobkins, & Huang, 2003; Proulx & Egeth, 2008), the impact of luminance contrast on memory is not clear. Given that attention is positively associated with memory, it is reasonable to assume that high luminance contrast is conducive to memory. This hypothetical relationship, however, has received little attention, especially in the Malaysian context. The present study attempts to address this gap

by examining the impact of luminance contrast on memory and attention.

Colour and Contrast

Colour is an electromagnetic radiant energy which provides a physical stimulus that enters the eye and generates the sensation of colour (Camgöz, 2000). Colour is characterized by three dimensions namely hue, saturation, and luminance. Hue is defined by wavelength (Hall & Hanna, 2004) and it is used to name colour (e.g., red, blue) and differentiate one colour from the others (Hill, 2001). Saturation, refers to the measure of the intensity of the colour (Camgöz, 2000), while luminance describes the degree of darkness or lightness of the colour (Mehta & Zhu, 2009). The change in any one of the three dimensions can produce a different sensation of a single colour (Camgöz, 2000).

Colour is one of the important aspects that can affect consumers' behaviour. For example, Seo (2010) examined the impact of colour on consumers' attentive behaviours and found that consumers spent significantly longer time to view the products with monochromatic colour packaging than product with complementary colour and the complementary-analogous colour. Moreover, participants rated the packaging with monochromatic colour combination higher quality and freshness.

Camgöz (2000) examined the impacts of hue, saturation, and brightness on university students' preference and attention. Participants were instructed to view colour squares with different levels of hues, saturations, and brightnesses that presented on eight background colours. Then, they were asked to choose a colour square that attracts the most attention, and the preferred one on the presented background colour. The result showed that brightness (luminance) and saturation levels are the most important dimensions in attracting attention and preference (Camgöz, 2000).

Contrast refers to the comparison that emphasizes differences between two areas of the visual field (Camgöz, 2000; Hill, 2001).There are two types of contrast, luminance contrast and colour/ chromatic contrast (Hill, 2001). Colour contrast indicates the differences between hue (or wavelength) of the two different areas (Hill, 2001). For instance, the combination of blue with a wavelength of 400nm and red with a wavelength of 730nm has higher colour contrast than the combination of green with a wavelength of 525nm and yellow with a wavelength of 555nm (Hill, 2001). Luminance contrast, on the other hand, compares the difference of light reflected from different areas. It can be calculated by the formulae (Hill, 2001):

$$\text{Contrast} = \frac{luminance_{maximum} - luminance_{minimum}}{luminance_{maximum} + luminance_{minimum}} \text{ and;}$$

$$\text{Contrast} = \frac{luminance_{object} - luminance_{background}}{luminance_{background}}$$

It is important to note that a combination of colour with high colour contrast does not necessary produce high luminance contrast and vice versa. For example, the combination of green and yellow which has low colour contrast may produce a high luminance contrast if the green is a deep forest green and the yellow is bright neon yellow (Hill, 2001). However, both types of the contrast can enhance our vision because they help us to discriminate the object from the background (Camgöz, 2000).

The Effect of Luminance Contrast

The impact of luminance contrast has been studied extensively. This is because human's eyes are more sensitive to luminance contrast than chromatic contrast (Camgöz, 2000). Indeed, studies have shown that patterns with higher (vs. lower) luminance contrast are more accurately recognized (Sclar & Freeman as cited in Pashler et al., 2003). Moreover, luminance contrast has been found to improve information processing (Hill, 2001) and attention (Pashler et al., 2003).

Proulx and Egeth (2008) conducted a study to investigate the effect of luminance contrast on attention. Participants watched a display of bars and were instructed to press right button if the vertical target bar presents or press left button if the target does not present. The bars displayed on the first trial were similar in lu-

minance level, while the bars displayed in the second trial were presented with different luminance level. The response time, correct responses, and incorrect responses were recorded. The researchers found that participants gave priority to bright stimulus even when the stimulus is irrelevant to the task. The results suggest that our visual system pays more attention to high than low contrast items (Proulx & Egeth, 2008).

The relationship between luminance contrast and attention is explained by biased competition theory of attention. This theory suggests that objects compete for cortical representation in a mutually inhibitory network. The competition is biased in favor to some features of the object such as luminance contrast and size. In other words, our attention will give priority to the object with higher contrast and larger size by default (Pashler et al., 2003; Proulx & Egeth, 2008). Taken together, it is hypothesized that high luminance contrast may enhance attention.

Relationship between Attention and Memory

Attention and memory are important aspects of information processing. According to the bottom-up theory, the flow of information starts from the sensory store and the information will disappear unless it is being recognized or identified in the pattern recognition process. Attention plays an important role in the recognition process to determine what information to be recognized and filter out other unnecessary information. Studies have shown that attention is positively associated with memory (Clarke, 2012; Li, Christ, Johnson, & Cowan, 2015). Indeed, attention determines what to be retained with the limited memory capacity (Chun & Turke-Browne, 2007). Specifically, only stimuli that can be encoded and processed will be retained in memory.

Based on the findings of the facilitative effect of luminance contrast on attention and the positive relationship between attention and memory, it is reasonable to hypothesize that the luminance contrast can enhance memory. In other words, people are more likely to recall stimuli with high luminance contrast than those with low luminance contrast.

The Present Study

The main goal of the present study is to examine whether and how luminance contrast enhances memory. On the basis of literature, we hypothesized that high (vs. low) luminance contrast leads to higher attention and high (vs. low) luminance contrast leads to better memory performance.

METHOD

Participants

A total of 159 undergraduates participated in this study. They aged 18 to 25 years old (M = 22.04, SD = 14.26) and the majority of them were female (71.70%). Of them were 137 Chinese, 20 Indians, and 2 Malays. The participants mainly composed of psychology students (93.08%). All of them have normal eyesight with or without the aid of spectacles.

Measurements

Selective attention. Selective attention was measured by the modified d2 test of attention (Brickenkamp & Zilmer as cited in Desnoyers & Arpin-Cribbie, 2015). Selective attention was determined by the capacity to focus on the target symbol—the letter "d" with only two dots located either individually or in pairs above and below the letter (see Figure 1a)—while suppressing the awareness to the distractors which were visually similar to the target (Brickenkamp as cited in Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribeiro, & Tidow, 2008). The original d2 test is a paper-and-pencil test that consisted of 14 lines of symbols. Each line has 47 randomly arranged symbols which made up of letter "d" and "p" with one to four dots located either above and/or below the letter.

In the present study, a shorter version consisted of 15 questions with 9 symbols on each was used (see Figure 1b for sample question). In addition, the test was conducted on computer and the questions were displayed one at a time on the screen. Participants were instructed to identify and indicate the number of target symbols using a keyboard. For example, participants are supposed to press the numerical key "2" if there are two target symbols. Participants were given 5s to respond and were automatically directed to next question after 5s or after the participant pressing a numerical key. The test took 75s to complete. The scoring was done by calculating the total number of correct responses of the participants. The higher score indicates better selective attention performance (Brickenkamp, Merten, & Hänsgen, 1997).

(a) (b)

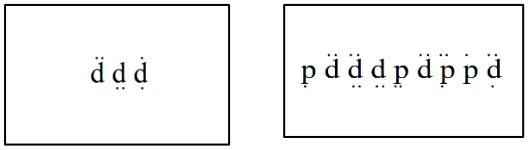

Figure 1. (a) The example of target symbols of attention test.
(b) The example question of attention test.

Memory. The modified word memory test (Berant, Kaufman, Leibovitz, Habot, & Bahar, 1995) was used to measure memory in the present study. The test consisted of presentation phase and recalling phase. In the presentation phase, 20 target words (e.g., around, brain, clothes) were randomly presented to the participants. The target words were presented in different luminance contrast level according to the participants' condition. For instance, the words were presented in high contrast for participants in the high luminance contrast group. Each word was presented for 3s with 0.2s intervals between the words. The participants were instructed to try their best to memorize the words.

Similar to the presentation phase, 20 words were presented to the participants in the recalling phase. The 20 words, however, consisted of 10 randomly selected target words and another 10 non-target words (words that were not presented in the presentation phase and were shown in black colour and white background). Participants were instructed to press the "y" button on the keyboard when the target word was displayed or press the "n" button when the non-target word was shown. One mark was given to each correct response. In contrast, if the participant pressed the "n" button when the target word was displayed, no mark was given to this incorrect response. The number of correct response was summed up. The higher score indicates better memory performance.

A pilot study was conducted to examine if the target words and non-target words have an impact on memory performance. Results showed that there was no significant difference in recalling target words and non-target words.

Luminance Contrast. Three luminance contrast levels (high vs. moderate vs. low) were used. Following past studies (e.g., Hill, 2001), the three levels were characterized by luminance contrast magnitude of 0.5, 0.3, and 0.1. Specifically, the luminance contrast magnitude was manipulated by changing the luminance level of the background while keeping the luminance level of the text constant. Table 1 shows the luminance level of background and text and the luminance contrast level of each condition.

Table 1.
Luminance level of font and background and luminance contrast level for the three conditions.

Condition	Luminance level of background	Luminance level of text	Luminance contrast level
Low	83	125	0.1
Moderate	96	125	0.3
High	113	125	0.5

Procedure

The software PsychoPy (Jonathan, 2007) was used to prepare the experimental programs. The study was conducted at a computer lab in a group of 4 to 12 students. Upon their arrival, participants were randomly assigned to one of the three luminance contrast conditions. Participants were instructed to press the spacebar key if they agree to participate in the study and begin the experiment or press "ESC" key to quit the experiment.

The experiment consisted of three parts. First, after giving their consent, the participants reported their demographic information and followed by the trial memory test to ensure participants understand the memory test. The trial was identical to the actual memory test in which participants were shown three words and then followed by the recalling phase. However, the target words in the trial were presented in black colour and white background. After the trial, participants proceeded to the presentation phase of the actual memory test in which they were shown the 20 target words that demonstrated in different luminance level. Then, participants were administered the attention test. Finally, in the recall phase of the actual memory test, participants were instructed to identify if the words were shown in the presentation phase (see Figure 2). The experiment took approximately 25 minutes.

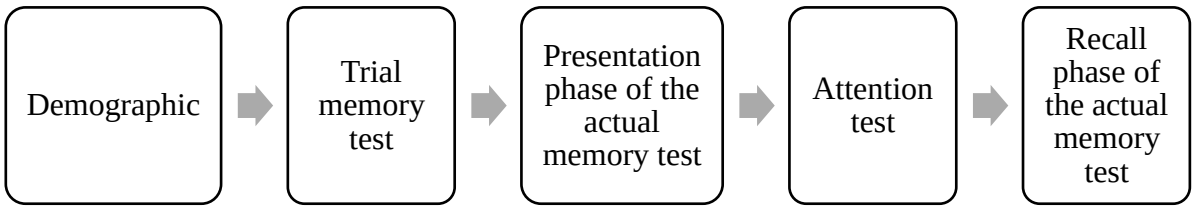

Figure 2. The procedure of the experiment.

RESULTS

Table 2 shows the means and standard deviation for memory performance and attention score for each level of luminance contrast. Pearson correlation analysis was conducted to examine the relationship between participant's memory performance and attention score. The result showed that the association between memory and attention was not statistically significant, $r(157) = -.038$, $p = .63$.

A multivariate analysis of variance (MANOVA), luminance condition served as the independent variable and memory and attention served as the dependent variables, was performed to examine the impact of luminance contrast on memory performance and attention. The results indicated a significant effect of luminance contrast, Wilks $\lambda = .894$, $F(4, 310) = 4.45$, $p = .002$, $n_p^2 = .054$. Tests of between-subject effects showed that luminance contrast had significant effect on memory, $F(2, 156) = 5.51$, $p = .005$, $n_p^2 = .066$.

An inspection of the mean scores for memory performance with Bonferroni correction indicated that the high luminance contrast group ($M = 17.77$, $SD = 1.56$) was significantly higher than the low luminance contrast group

(M = 16.54, SD = 2.56). Moreover, the moderate contrast group (M = 17.62 SD = 1.97) scored higher than the low luminance contrast group. There was no significant difference between the high luminance contrast group and moderate contrast groups.

On the other hand, analysis on attention found no significant effect of luminance contrast, $F(2, 156) = 3.00$, $p = .053$, $n_p^2 = .037$. However, planned comparison using Tukey HSD test showed that the mean for high luminance contrast group (M = 7.05, SD = 1.47) was significantly higher than low luminance contrast group (M = 6.22, SD = 2.22).

Table 2.
Mean and standard deviation for memory performance and attention for each level of luminance contrast

	Memory		Attention	
Group	Mean	SD	Mean	SD
High	17.77	1.56	7.57	1.47
Moderate	17.62	1.97	6.53	1.50
Low	16.54	2.56	6.23	2.22

DISCUSSION

The objective of the present study was to investigate the impact of luminance contrast on attention and memory. On the basis of past findings, it is hypothesized that people are more likely to have higher attention and memory performance when the stimuli are presented in high (vs. low) luminance contrast.

In contrast to past findings, our results showed that luminance contrast level, in general, does not have an impact on attention. However, planned comparison showed that participants in the high luminance contrast group scored significantly higher in attention test than their counterparts in the low luminance contrast group. The high (vs. low) luminance contrast group performed better in attention because an object with high contrast could guide attention (Parkhurst & Niebur, 2004; Pashler, et al., 2003; Proulx & Egeth, 2008; Wolfe, Butcher, Lee, & Hyle, 2003).

Our results also found no significant relationship between attention and memory performance. The finding is contradicted with previous studies that found a positive relationship between attention and memory (Belopolsky, Kramer, & Godjin, 2008; Schmidt, Vogel, Woodman, & Luck, 2002). According to the biased competition theory of attention, the properties of the visual inputs such as luminance are analyzed locally. Our attention will be directed to the objects with most salient properties (Koch & Ullman as cited in Einhäuser & König, 2003). Stimuli that are attended, whether voluntarily or involuntarily, would be transferred into memory (Schmidt et al., 2002). Therefore, the insignificant relationship between attention and memory indicates that the stimuli presented failed to capture participants' attention. In other words, the properties of the stimuli (i.e., three levels of luminance contrast) were not salient enough, at least, to our participants. When the luminance contrast of objects does not differ notably, the effect of luminance contrast on attention could be more effectively detected by dynamic luminance: sudden luminance change of an object (Spehar & Owen, 2012). The dynamic luminance changes attract the attention more effectively than the static luminance contrast of the same magnitude (Cole, Kuhn, Heywood, & Kentridge, 2009; Spehar & Owen, 2012). Therefore, one of the future directions to re-examine the impact of luminance contrast on attention is to apply dynamic luminance change rather than a constant luminance contrast level.

Interestingly, consistent with our assumption, a significant impact of luminance contrast on memory performance was observed in the present study. Specifically, both high and moderate luminance contrast groups scored significantly higher than low luminance contrast group in the recall task. The results indicate that moderate and high luminance contrast can benefit our memory while objects with low luminance contrast are less likely to be recalled.

Limitations and Future Directions

This study is subject to a number of limitations. First, the instruction of the attention test is not clear. Participants were instructed to identify the letter "d" with only two dots located either individually or in pairs above and below the letter. Inspection of data, however, indicates that most of the participants failed to identify the letter "d" with one dot above and another below as one of the target symbols. Moreover, no feedback was given in the trial test. Participants have no idea if their responses are correct and hence may not have the motivation to perform during the attention test. The overlook of the target symbol and low motivation not only impairs participants' performance but also biases the results. This partly explains why our results are not consistent with the past findings. Future studies are encouraged to provide examples of target symbols in the instruction. Also, providing feedback to participants' response to the trial test by showing the correct answer may help participants to understand the task better.

There was no control group in the current one-group post-test-only design. The impact of luminance contrast remains open without directly comparing the experimental group and control group. In the same vein, factors that may confound the effect of luminance contrast, such as individual differences in cognitive ability, were not taken into account in the present study. Moreover, the experiment was conducted in a laboratory setting. It is not clear to what extent the findings can be generalized to other contexts. More studies using different research design are warranted to further examine the impact of luminance contrast on other domains such as consumer behaviour and learning behaviour.

It is also important to note that the colour combination that employed in the current study only represents a small portion of the visual spectrum. There is a possibility that the effect of luminance contrast on memory performance may be enhanced (or reduced) when using other colour combinations. Future studies can investigate the effect of luminance contrast using different colour combinations to examine whether the effect of luminance contrast would vary among the colours. We also recommend researchers to assess the effect of luminance contrast using more complex visual stimuli. This is because the advertisement in our daily life is usually a combination of various elements and graphics.

Finally, the allocated respond time (5s) to the attention test could be too short. In the original test, respond time for each question that contains 47 symbols was 20s. While in the present study each question only contains 9 symbols, it is believed that 5s should be appropriate. Researchers may consider other time intervals to ensure that participants have enough to respond.

Despite the limitations mentioned above, the present study has both theoretical and practical contributions. Theoretically speaking, our results extend our understanding of the relationship between luminance contrast and memory performance. Our findings demonstrate that high and moderate luminance contrast levels are conducive to memory. Thus, advertisers are advised to use different luminance contrast levels to fulfill their goals. For example, designers may adjust the level of luminance contrast according to the level of importance. While using a lower luminance contrast for general information, important information shall be presented in high luminance contrast to make the latter more notable (Ware, 2013).

CONCLUSION

The present study examined the effect of luminance contrast on attention and memory. High luminance contrast was found to improve attention while moderate to high luminance contrast can facilitate memory performance. This result can be a guideline for advertiser and designers to enhance effectiveness and attractiveness of their products.

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